

# DESIGN AND TEST OF A REMOTE QUICK-CONNECT SYSTEM FOR MULTIPURPOSE EXCAVATORS

P.K. LAIRD, P. ST. LOUIS, D.T. ATKINSON,  
R. KLEINHANS, J. SPECTOR, D.L. REED

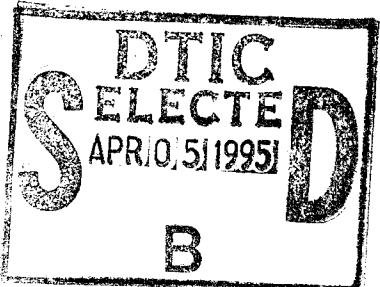
HQ AFESC/RDCP  
AIR FORCE ENGINEERING AND SERVICES CENTER  
TYNDALL AFB FL 32403-6001

AUGUST 1988

FINAL REPORT

SEPTEMBER 1985 - SEPTEMBER 1987

19950404 093



APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED



ENGINEERING & SERVICES LABORATORY  
AIR FORCE ENGINEERING & SERVICES CENTER  
TYNDALL AIR FORCE BASE, FLORIDA 32403

NOTICE

PLEASE DO NOT REQUEST COPIES OF THIS REPORT FROM  
HQ AFESC/RD (ENGINEERING AND SERVICES LABORATORY).  
ADDITIONAL COPIES MAY BE PURCHASED FROM:

NATIONAL TECHNICAL INFORMATION SERVICE  
5285 PORT ROYAL ROAD  
SPRINGFIELD, VIRGINIA 22161

FEDERAL GOVERNMENT AGENCIES AND THEIR CONTRACTORS  
REGISTERED WITH DEFENSE TECHNICAL INFORMATION CENTER  
SHOULD DIRECT REQUESTS FOR COPIES OF THIS REPORT TO:

DEFENSE TECHNICAL INFORMATION CENTER  
CAMERON STATION  
ALEXANDRIA, VIRGINIA 22314

## UNCLASSIFIED

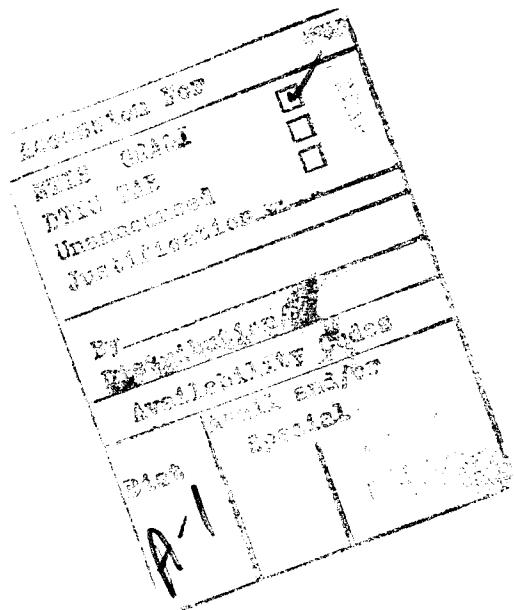
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>		1b. RESTRICTIVE MARKINGS <b>NONE</b>			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) <b>ESL-TR-88-43</b>		5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION <b>Air Force Engineering and Services Center</b>		6b. OFFICE SYMBOL ( <i>If applicable</i> ) <b>HQ AFESC/RDCE</b>	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) <b>Tyndall AFB, FL 32403-6001</b>		7b. ADDRESS (City, State, and ZIP Code)			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION <b>Air Force Engineering &amp; Services Cen.</b>		8b. OFFICE SYMBOL ( <i>If applicable</i> ) <b>HQ AFESC/DEY</b>	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) <b>Tyndall AFB, FL 32403-6001</b>		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO. <b>64708F</b>	PROJECT NO. <b>2621</b>	TASK NO. <b>20</b>	WORK UNIT ACCESSION NO. <b>22</b>
11. TITLE ( <i>Include Security Classification</i> ) <b>Design and Test of a Remote Quick-Connect System for Multipurpose Excavators</b>					
12. PERSONAL AUTHOR(S) <b>Laird, P.K.; St.Louis, P.; Atkinson, D.T.; Kleinhans, R.; Spector, J.; Reed, D.L.</b>					
13a. TYPE OF REPORT <b>Final</b>	13b. TIME COVERED <b>FROM 85-09 TO 87-09</b>	14. DATE OF REPORT (Year, Month, Day) <b>August 1988</b>		15. PAGE COUNT <b>114</b>	
16. SUPPLEMENTARY NOTATION Availability of this report is specified on reverse of front cover.					
17. COSATI CODES		18. SUBJECT TERMS ( <i>Continue on reverse if necessary and identify by block number</i> ) <b>Rapid Runway Repair Remote Tool Attachment Quick-Connect Tool Carrier Quick Disconnect Multipurpose Excavator (Cont'd)</b>			
19. ABSTRACT ( <i>Continue on reverse if necessary and identify by block number</i> ) Quick repair of bomb-damaged runways is a task being addressed by an Air Force program entitled "Rapid Runway Repair" (RRR). Increased emphasis is being placed on the design of mechanized equipment that will expedite repairs and, at the same time, ensure the safety of the operator exposed to the hazardous postattack environment. The objective of the effort described in this report is to provide a system which allows the operator to rapidly and remotely change tools which are attached to the boom of the excavator. The tool exchange process involves an automatic hydraulic connection as well as the mechanical attachment of three tools: an excavator bucket, a hydraulic hammer, and a hydraulic compactor plate. The "Quick-Connect" system also includes a tool-carrying device for transporting these tools to the job site. (Cont'd)					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>		
22a. NAME OF RESPONSIBLE INDIVIDUAL <b>PAUL K. LAIRD</b>			22b. TELEPHONE ( <i>Include Area Code</i> ) <b>904-283-6316</b>	22c. OFFICE SYMBOL <b>HQ AFESC/RDCP</b>	

18. Continued  
Excavator  
Remote Hydraulic Connector

19. The Air Force awarded and managed two separate contracts to obtain two independent Quick-Connect system designs. These designs were developed, fabricated, and installed on multipurpose excavators for Air Force test and evaluation. The program established the technical feasibility of remotely changing excavator tools in less than 1 minute and demonstrated the excavator's capability to transport three attachments on a tool carrier.

In its three appendixes, the report details the results of the two independently conducted design efforts (Appendix A and B), and documents the test and evaluation of Design "A" (Appendix C).



## PREFACE

The report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory (AFESC/RDCP)), Tyndall Air Force Base, Florida. The report was written to combine and publish, under single cover, three technical reports which were prepared during the Quick-Connect Program (PE 64617F, JON 26212022).

Appendix A was prepared by Consolidated Technologies, 5070 Oakland Street, Denver, Colorado 80239, under Contract Number F08635-85-C-0232. Appendix B was produced by Foster-Miller, Inc., 350 Second Avenue, Waltham, MA 02254 under Contract Number F08635-85-C-0233. Appendix C was prepared by the BDM Corporation, 7915 Jones Branch Drive, McLean, Virginia 22101 under Contract Number F08635-84-C-0815.

This report summarizes work done between October 1985 and September 1987. HQ AFESC/RDCP project officers were Mr. Paul K. Laird and Mr. Edgar F. Alexander.

This report documents the design, fabrication, testing, and analysis of two mechanized quick tool change devices. These devices permit remotely-controlled (mechanical and hydraulic) connection of tools to be attached to the boom of an Air Force multipurpose excavator.

This report has been reviewed by the Public Affairs (PA) Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

*Paul K. Laird*

PAUL K. LAIRD  
Project Officer

*James R. Van Orman*  
JAMES R. VAN ORMAN  
Deputy Director, Engineering  
and Services Laboratory

*Charles W. Manzione*

CHARLES W. MANZIONE, Capt, USAF  
Acting Chief, Engineering Research  
Division

## TABLE OF CONTENTS

Section	Title	Page
I	INTRODUCTION.....	1
	A. PURPOSE.....	1
	B. BACKGROUND.....	1
	C. OBJECTIVES.....	2
	D. APPROACH.....	2
II	DISCUSSION.....	3
	A. ORGANIZATION OF DATA.....	3
	B. OBSERVATIONS - DESIGN A.....	3
	C. OBSERVATIONS - DESIGN B.....	3
	D. GENERAL COMMENTS.....	4
III	SUMMARY.....	5
	A. PERFORMANCE.....	5
	B. RECOMMENDED CHANGES.....	5
	C. TECHNOLOGY APPLICATION.....	6
	D. CONCLUSION.....	6
APPENDIX		
A	DESIGN "A" QUICK-CONNECT SYSTEM.....	7
B	DESIGN "B" QUICK-CONNECT SYSTEM.....	33
C	DESIGN "A" QUICK-CONNECT TEST.....	89

## LIST OF FIGURES

Figure	Title	Page
A-1	Quick-Coupler Hitch and Adapter on Hydraulic Hammer with Locking Pin Retracted.....	17
A-2	Quick Coupler Hitch and Adapter on Hydraulic Compactor with Locking Pin Extended.....	18
A-3	Cross Section of Hydraulic Cylinder Used as Quick-Coupler Lock.....	18
A-4	Quick-Coupler Hitch Modified with Tapered Plate....	19
A-5	Quick-Coupler Hitch with Modified Lock Pin.....	20
A-6	Quick-Coupler Hitch and Bucket with Contamination Guards.....	21
A-7	Quick-Connect Actuators Mounted in Quick-Coupler Hitch.....	23
A-8	Quick-Connect Cross Sections Coupled and Uncoupled.	23
A-9	Quick-Connect Nipple Housings with Protective Rubber Boot.....	24
A-10	Quick-Connect Actuators During Contamination Test Before Excess Contamination Was Brushed Away.....	26
A-11	Carrying Device With Tools.....	27
A-12	Carrying Device in Transport Position.....	28
B-1	Standard John Deere 690C Bucket/Linkage.....	38
B-2	TAC Concept in a John Deere 690C Geometry.....	39
B-3	TAC Assembly.....	45
B-4	A Cross Section through the Toggle Pivot Centerline.....	46
B-5	Tools with Attachment Ears.....	47
B-6	Toggle Mechanism Totally Engaged in Ears.....	48
B-7	Air-Cleaning System and Filter Plate for Face Seal.	49
B-8	Cross Section View of Male Coupler.....	52
B-9	Cross Section View of Female Coupler.....	52
B-10	Hydraulic Tubes on Excavator Stick.....	54
B-11	Male/Female Connection at Bottom of Hydraulic Tubes.....	54
B-12	Hydraulic Tube Activation Cylinders.....	56
B-13	Hydraulic Connect/Disconnect Activation Cylinders..	57
B-14	Seal Components in Male Quick-Connect..	58
B-15	Seal Components in Female Quick-Connect.....	59
B-16	Original Proposed Tool-Carrier Concept.....	62
B-17	Back and Side Views of the Tool Carrier.....	63
B-18	Loaded Tool Carrier.....	64
B-19	Support System for Bucket Location.....	65
B-20	Support System for Compactor Plate.....	66
B-21	Support System for the Hydraulic Hammer.....	67
B-22	Loaded Tool Carrier Supported by John Deere Excavator.....	68
B-23	Modifications to the Excavator Stick.....	72
B-24	Independent Hydraulic Power Supply and Its Location.....	73
B-25	Controls for Independent Hydraulic Power Supply....	74
B-26	Hoses Running from the Hydraulic Power Supply.....	74

LIST OF FIGURES  
(Concluded)

Figure	Title	Page
B-27	Hoses Running Over the Top of the Boom.....	75
B-28	Hose Emerging from Stick and Running to TAC Lock Pin.....	75
B-29	Hydraulic Tubes and Stiffeners.....	76
B-30	TAC Linkage Attached to Stick.....	76
B-31	Ear Assembly Welded to Compactor.....	77
B-32	Mated Hydraulic Quick-Connects.....	78
B-33	Armored Hose on Hydraulic Hammer.....	78
B-34	Step No. 1 - Place Tool-Carrying Device on the Ground.....	82
B-35	Step No. 2 - Pick Up the Bucket.....	82
B-36	Step No. 3 - Pick Up the Hydraulic Hammer.....	83
B-37	Step No. 4 - Pick Up the Hydraulic Compactor.....	83
B-38	Step No. 5 - Pick Up the Tool-Carrying Device.....	84
B-39	Excavator Tramming Over Unpaved Terrain With Loaded Tool Carrier.....	85
B-40	Conditions Causing Fracture of the Power Link.....	86
B-41	Modification for Avoiding Toggle Link Jamming.....	86
C-1	RRR Excavator With Tool Carrier Attached.....	92
C-2	View of Tool Changing Process.....	94
C-3	Tool Carrier Pickup and Positioning.....	96
C-4	Long-Term Compaction Plate Use.....	99
C-5	Long-Term Hammer Use.....	100

## LIST OF TABLES

Table	Title	Page
A-1	SEQUENCE OF OPERATIONS.....	12
C-1	TOOL CHANGE TIMES.....	94
C-2	ADDITIONAL TOOL CHANGE TIME TEST RESULTS.....	95
C-3	TOOL CARRIER PICKUP AND POSITIONING TIMES.....	97

SECTION I  
INTRODUCTION

A. OBJECTIVE

The objective of the Quick-Connect program at the Air Force Engineering and Services Center (AFESC) was to produce an excavator tool change system to eliminate handling bulky attachment hardware and permit the operator to remain inside the armor protected cab. Accessories could then be changed in seconds, rather than minutes.

To improve the efficiency of the RRR multipurpose excavator, a concept was developed in 1984 for a tool change system with the following features:

- o Design allows the typical operator to complete a tool change within 1 minute.
- o Tool change is remote.
- o Tool carrier can be transported by the excavator.
- o Tool carrier prepositions bucket, compactor, and impact hammer to facilitate tool changes.
- o Design provides for environmental protection of mechanical and hydraulic connections.

B. BACKGROUND

Maximum efficiency obtained from construction equipment saves time and money for all categories of equipment users. For the military, however, the need goes much deeper. Tactical Air Force (TAF) Statement of Operational Need (SON) 319-79 requires that equipment, materials, and procedures must be developed to provide a rapid runway repair (RRR) capability for the airbase postattack environment. To respond to this SON, a program was initiated by the AFESC Engineering and Services Laboratory (RD) in 1979. In 1986, the Rapid Runway Repair Program Office (DEY) was formed within the AFESC to assume management responsibility of the RRR program. RD continued to conduct research to benefit future RRR developments and provided engineering support to ongoing DEY programs.

One requirement in TAF SON 319-79 calls for RRR equipment to be air transportable. This requires maximum use of multipurpose construction equipment to reduce the number of vehicles that must be airlifted. Multipurpose equipment must be able to transport extra attachments to the job site where these diverse accessories are to be removed and replaced as the job progresses.

Another requirement contained in the SON is that craters must be repaired in minimum time. The postattack environment and the constant threat of follow-on attacks place extreme demands on available runway repair equipment assets. Efficient RRR equipment saves facilities, equipment and lives, and is essential to mission accomplishment--the rapid restoration of sortie generation. In the early years of the RRR program, the Air Force developed a multipurpose excavator; equipment enhancements now being developed are aimed at improving excavator performance.

Aside from the requirement that the multipurpose excavator tool change system incorporate time-saving features, it must also permit remote operation. Bomb-damaged runways will likely be strewn with unexploded ordnance (UXO), making it extremely hazardous for the equipment operator to leave the armor protected cab to accomplish a tool change. To eliminate the need for a separate tool-transporting vehicle to traverse the UXO infested area, the development of a tool carrier is necessary if the excavator is to carry its own tools to the job site.

#### D. SCOPE/APPROACH

Contracts to design, build, and demonstrate the Quick-Connect System were awarded to two contractors in September 1985. The contractors worked independently to provide two different and complete systems compatible with the JD690C excavator. Funding was provided by the AFESC Rapid Runway Repair System Program Office (DEY), while contract management and technical direction were provided by the AFESC Engineering and Services Laboratory (RD).

This report consolidates two technical reports which document two contractor-developed designs and a third report which describes the AFESC test and evaluation of the Quick-Connect hardware. The body of this report provides an overview of the Quick-Connect program and makes recommendations based on the findings of three independent technical reports (included in their entirety as Appendixes A, B, and C) prepared during the program.

## SECTION II

### DISCUSSION

#### A. ORGANIZATION OF DATA

The two hardware designs will be described as Designs "A" and "B." The Design A and Design B hardware are described in Appendix A and Appendix B, respectively. The test report for Design A testing is contained in Appendix C; the results of Design B testing are included in Appendix B. The discussion of each design will focus on the system's three major components: (1) the tool attachment, (2) the hydraulic attachment, and (3) the tool carrier.

#### B. OBSERVATIONS - DESIGN A

The Design A tool attachment is similar to the standard tool adaptor on the JD690C Multipurpose Excavator and hardware modifications were minor. The standard adaptor requires that a locking pin be manually removed and reinstalled during every tool change. The Design A tool attachment uses a hydraulic actuator to install and remove the pin as illustrated in Figures A-1 and A-2.

The Design A hydraulic connection uses a unique housing to remotely operate quick-release couplers which are normally used for manual connections. The housings position and move the male and female connector halves, as illustrated in Figure A-8, to connect and disconnect the couplers. Each hydraulic coupler housing is covered with a rubber dust cover, as shown in Figures A-7 and A-9. Slits in the rubber cover allow the connectors to extend through the covers during a connection.

The Design A tool carrier is inferior to the Design B carrier in that the tools are not canted toward the center. The parallel arrangement of the tools forces the excavator to approach the carrier from the side and swing the cab and boom to the side to gain access to the tool carrier and tools. This sideways approach is required to permit left or right movement of the excavator (relative to the tools) while remaining in line with the tools. If the standoff between the tool carrier and the excavator is misjudged, it is necessary to move the excavator away and return to a new position. This factor made tool change times vary and the times frequently exceeded 1 minute.

#### C. OBSERVATIONS - DESIGN B

Design B required extensive modifications to both excavator and the tool adaptor (see Figures B-12, B-22, and B-23).

Surfaces of the hydraulic connectors exposed to potential contaminants are pushed beyond a seal inside the connectors to

prevent the flow of oil accross the dirty surfaces (see Figures B-14 and B-15).

The adaptors on the tools and the tool carrier were well positioned for visibility and were readily accessible to the adaptor on the boom. The hammer and bucket were canted toward the center of the tool carrier to allow easy tool-to-tool adaptor alignment (see Figure B-21). An additional benefit of the canted tool arrangement was that the excavator could approach the tool carrier either head-on or from the side--whichever was more convenient. The head-on approach required less time to adjust standoff from the carrier--a parameter which must be correct for a smooth tool change.

#### D. GENERAL COMMENTS

Designs A and B had a switch for the mechanical connection, a separate switch for the hydraulic connection, and operating the switches in the wrong sequence could damage the hydraulic connectors. A conveniently located single switch should be used, which automatically locks and unlocks the hydraulic attachment and the tool attachment in the proper sequence.

The operator was unable to tell when the tool connections were successfully completed. To correct this, an indicator is needed which will provide a positive indication of the locked/unlocked status of the mechanical and hydraulic connections.

The tool carriers had small cradles to help guide the tools into place and to prevent tools from sliding off the tool carrier during transport. Larger cradles would require less precision when placing tools on the carrier. A secondary benefit would be improved retention of the tools during transport over uneven terrain.

## SECTION III

### SUMMARY

#### A. PERFORMANCE

Both designs met the original goals for remote tool changes to be accomplished within 1 minute. The Design A coupler initially failed to meet the 1-minute criteria, but was retested using the Design B tool carrier (tools canted toward center) and times were reduced to well below 1 minute. The Design B tool carrier provided better tool positioning, while both carriers could be lifted and transported by the excavator. Neither design met the requirement to environmentally protect the hydraulic connections.

#### B. RECOMMENDED CHANGES

The Design A tool attachment and the Design B tool carrier are recommended as a baseline for the future Quick-Connect design work. The Design A hydraulic couplers were well located but improvements are needed to resolve the problems identified in Section II of this report and in the Appendix C test report. The final design of the Quick-Connect system should be thoroughly retested to insure that system reliability is acceptable. The areas requiring change are summarized as follows:

- o Place the lock/unlock switch in a more convenient location.
- o Provide lock/unlock status indicator.
- o Install a single lock/unlock switch which assures the proper sequence for mechanical and hydraulic connections.
- o Locate hydraulic couplers in protected areas within the tool adapter.
- o Provide an effective dirt shield for hydraulic couplers.
- o Install more rugged mounting hardware and connector housing to prevent bending and misalignment.
- o Shock-isolate the hydraulic couplers from the tools. (When the connectors are rigidly attached to the tools, the relative motion between the vibrating tool and the boom place a destructive cyclic loading on O-rings in the hydraulic connectors.)
- o Orient tools on the tool carrier to permit boom-to-tool alignment without repositioning the excavator.

- o Provide larger cradles for tools on tool carrier to facilitate tool placement and tool retention on the tool carrier.

One additional feature which would reduce the probability of equipment downtime is a manual backup to the automatic quick-connect. Should a component fail, the option will exist to connect a tool manually and maintain use of the excavator and tool until circumstances allow the failed component to be repaired.

#### C. TECHNOLOGY APPLICATION

The lessons learned and recommended changes contained in this report and the Appendixes should provide equipment designers with information to assist future development of Quick-Connect systems.

The simplicity of the remote tool adaptor make it feasible to be included as a standard feature on all new excavators. The tool carrier and many accessories require no hydraulic connections. In these cases, the benefits of simplified and remote tool change would be available without the inclusion of the remote hydraulic connection. When hydraulic tools are needed, manual hydraulic quick couplers would be adequate for many users.

The feasibility of using a remote hydraulic connection would depend on the application. If a hazardous environment exists or a remote-controlled vehicle is needed--then the remote connections are essential. When production quantities are low, this feature will cost more and require more maintenance than a manual attachment. For normal construction applications, the use of manual quick-release hydraulic fittings may suffice. Additional development and mass production of remote hydraulic couplers will eventually make it as simple and practical as the remote tool attachment.

The tool carrier is a feature which will require tailoring to accommodate the particular set of tools to be used. In nonhazardous environments, a trailer with surface features for tool positioning may be more desirable.

#### D. CONCLUSION

The Remote Quick-Connect program demonstrated that remote tool changes can be accomplished within 1 minute and that the tool carrier concept is feasible. The two designs provide features for a baseline design which could incorporate the improvements necessary to meet all of the technical requirements listed in Section I, Paragraph C of this report. The remote tool attachment should become a standard feature on commercial and military equipment, while the remote hydraulic connections require additional development and may only be practical for operations in hazardous environments.

APPENDIX A

DESIGN "A" QUICK-CONNECT SYSTEM

Paul St.Louis

Consolidated Technologies Corporation  
5070 Oakland Street  
Denver, Colorado 80239

SECTION I  
INTRODUCTION

A. OBJECTIVE

The objective of this effort by Consolidated Technologies was to design, fabricate, test and analyze a prototype quick-connect/disconnect system for tool-to-tool changes on the USAF Rapid Runway Repair (RRR) Excavator.

B. BACKGROUND

1. Program Goal

The goal of the Rapid Runway Repair (RRR) Program is to efficiently repair bomb-damaged runways so that aircraft operations can be resumed quickly. Increased remote mechanization of the RRR operation will minimize the requirement for personnel to work outside the protected equipment cabs and will reduce the time required for tool-to-tool changes.

2. Definitions

The mechanized Quick-Connect System is a tool-carrying device and a quick tool change device that remotely makes both mechanical and hydraulic connections for attachment tools fitted to the boom of the RRR excavator.

For the purpose of this report, a quick-connect is defined to be a hydraulic quick-acting coupler. Likewise, a quick-coupler is defined to be a mechanical device for affixing an attachment tool to the excavator arm and consists of two parts. The quick-coupler hitch remains pinned on the excavator arm. The quick-coupler adapter is permanently joined to an attachment tool, such as the hydraulic impact hammer, a hydraulic vibrating plate-type compactor and a 48-inch wide excavator bucket.

C. SCOPE

This section covers the project objectives and background. Section II, Developmental Requirements, discusses the developmental requirements and issues. Section III, Subsystem Developmental Testing and Evaluation, describes each prototype system and summarizes the testing program. Section IV presents the conclusion.

## SECTION II

### DEVELOPMENTAL REQUIREMENTS

#### A. SUBSYSTEMS

As the first step in the development of the Mechanized Quick-Connect System, the system was divided into three subsystems. The developmental requirements of each subsystem were analyzed and separate developmental issues were identified. The three subsystems were the Quick-Coupler Subsystem, the Quick-Connect Subsystem and the Carrying Device for the attachment tools.

#### B. QUICK-COUPLER SUBSYSTEM

##### 1. Technical Requirements

The Statement of Work (SOW) requires that the Mechanized Quick-Connect System allow one operator to complete a change of attachment tools in less than 1 minute without leaving the excavator cab and with no degradation in the excavator performance. The 1-minute time limitation included both the mechanical exchange of attachment tools and the completion of the hydraulic circuit. The sequence of operations required for the possible combination of attachment tool interchanges are outlined in Table A-1.

##### 2. Analysis

The preliminary analysis of the Quick-Coupler Subsystem focused primarily on the selection of the quick-coupler and the method of remote actuation. Alternative configurations of the quick-coupler were the use of the standard quick-coupler on the RRR excavator and attachment tools, the use of another commercially available quick-coupler, and design and development of a unique quick-coupler specifically for this system.

Hydraulic, electrical, and pneumatic methods were considered for the remote actuation of the Quick-Coupler and Quick-Connect Subsystems.

##### 3. Developmental Issues

Many issues were identified as critical to the development of the Quick-Coupler Subsystem.

###### a. Locking Means

Each type of quick-coupler has a means to mechanically lock the adapter and attachment tool to the hitch and excavator. This locking means, usually a pin, must be remotely actuated, positive in locking, and durable enough to withstand the forces generated by the operation of the hammer and compactor. The

remote actuation method must provide sufficient force to both extend and retract the lock pin under all operational conditions.

TABLE A-1. SEQUENCE OF OPERATIONS

---

INTERCHANGE BUCKET TO HYDRAULIC ATTACHMENT TOOL

- Position bucket on tool-carrying device
- Unlock bucket from quick-coupler hitch
- Disengage hitch from bucket
- Manipulate hitch into engagement with hydraulic attachment tool
- Lock hitch onto tool
- Lock hydraulic quick-connects
- Lift tool from tool-carrying device

INTERCHANGE ONE HYDRAULIC ATTACHMENT TOOL TO SECOND HYDRAULIC ATTACHMENT TOOL

- Position first hydraulic attachment tool on tool-carrying device
- Unlock hydraulic quick-connects
- Unlock first tool from quick-coupler hitch
- Disengage hitch from first tool
- Manipulate hitch into engagement with second tool
- Lock hitch onto tool
- Lock hydraulic quick-connects
- Lift tool from tool-carrying device

INTERCHANGE HYDRAULIC ATTACHMENT TOOL TO BUCKET

- Position hydraulic attachment tool on tool carrying device
- Unlock hydraulic quick-connects
- Unlock tool from quick-coupler hitch
- Disengage hitch from tool
- Manipulate hitch into engagement with bucket
- Lock hitch onto bucket
- Lift bucket from tool-carrying device

---

b. Component Placement

Another key developmental issue was component placement. To maintain maximum operator visibility of the hitch during all attachment tool exchange operations and decrease the potential for damaging any Quick-Connect Subsystem components, careful packaging of all components within the hitch and adapters was critical. Likewise, the quick-coupler actuating means and quick-connect components were required to be as small as possible but still meet the functional requirements.

c. Alignment

The alignment of the quick-coupler hitch with the adapter on each attachment tool was another important

developmental issue. To ensure proper engagement of both the locking means and the Quick-Connect Subsystem components, the alignment had to be positive, accurate, and repeatable.

### C. QUICK-CONNECT SUBSYSTEM

#### 1. Technical Requirements

The SOW required the Quick-Connect Subsystem to work in such adverse environmental conditions as sand, dirt, ice, clay, and rock without fluid contamination.

#### 2. Analysis

Because the hydraulic attachment tools require both a supply and a return line, two quick-couplers are required and each consists of two parts: a body which contains a locking ring and a nipple.

The key issues in the analysis of the Quick-Connect Subsystem were the design of the quick-connect and the means to prevent fluid contamination. The alternative sources for the quick-connects were to use a commercially available model or to design and manufacture one specifically for this application.

Three possible schemes to prevent contamination of the excavator hydraulic system by the quick-couplers were considered. These were to provide a cover which would prevent contamination accumulation on the quick-couplers or to allow contamination to accumulate and to remove it either mechanically or pneumatically with a jet of compressed air.

#### 3. Developmental Issues

Key considerations in the development of the Quick-Connect Subsystem were the mechanical and hydraulic requirements of the quick-connects and the mechanical and performance characteristics of the contamination prevention system.

##### a. Quick-Connect Requirements

Several factors were identified as important to the success of the quick-connects. The pressure and flow ratings of the quick-connects had to exceed the pressure and flow conditions of the application. Also, the design of the quick-connects had to be easily adaptable to remote actuation. In addition, both halves of the quick-connects had to be valved to prevent fluid spillage when uncoupled. Lastly, the quick-connects had to be reliable and leakproof when operating under the high shock and vibration loads which hydraulic hammer and vibrating plate-type compactors often generate.

### b. Contamination Prevention System

The contamination prevention system had to protect the hydraulic system of the excavator from the contaminants listed in the SOW and had to protect the quick-connect components from both contamination and damage while the excavator was used for digging. The system had to be reliable, easy to install and rebuild and effective with various contaminants and ambient conditions.

## D. CARRYING DEVICE

### 1. Technical Requirements

The SOW requires a full set of attachment tools be transportable by the carrying device using either a quick-coupler or a hook on the excavator boom. No degradation of excavator performance is allowed. Additionally, the carrying device is to maintain the proper orientation of all tools to minimize the time required for a tool exchange.

### 2. Analysis

The excavator performance is defined in MIL-E-29249. The excavator has a travel speed requirement of no less than 8 miles per hour on level pavement and a gradability requirement of negotiating a 30-percent grade on dry concrete or asphalt.

### 3. Developmental Issue

Developmental issues for the carrying device include balance, weight, safety, and orientation.

#### a. Balance

To minimize any detrimental moment loads on the excavator boom, the carrying device loaded with a full set of attachment tools, must be balanced about the quick-coupler adapter or other pickup device.

#### b. Weight

The design of the carrying device must provide sufficient structural strength and rigidity without adding unnecessary weight.

#### c. Safety

The design of the carrying device must provide a means to retain each attachment tool so the tools can neither slide, cause an imbalance, nor fall from the carrying device while it is being lifted or transported.

d. Orientation

Each attachment tool must be placed on the carrying device so that it will be convenient for rapid tool exchanges.

### SECTION III

#### SUBSYSTEM DEVELOPMENTAL TESTING AND EVALUATION

Each subsystem is summarized in terms of a descriptive overview, subsystem description, developmental testing, and field tests. Field test data are not presented. An evaluation of each subsystem compares its capabilities to the requirements of the SOW of the Mechanized Quick-Connect System and the goals of the RRR Program.

##### A. QUICK-COUPLER (MECHANICAL) SUBSYSTEM DEVELOPMENT

###### 1. Overview

A standard RRR quick-coupler was modified to include a hydraulically actuated lock pin and the bodies and actuators of the quick-connects within the hitch and the quick-connect nipples within each adapter.

###### 2. System Description

The standard quick-coupler was used for several design factors. While maintaining good visibility, the operator can engage the hook of the hitch on the bar of an attachment tool. A subsequent rolling motion of the hitch forces its alignment with the adapter. When the hitch is bottomed out on the adapter, alignment is positive and locking is achieved by linear displacement of the locking pin (Figures A-1 and A-2). In addition, both the hitch and the adapter have adequate space for mounting the quick-connect components in protected areas.

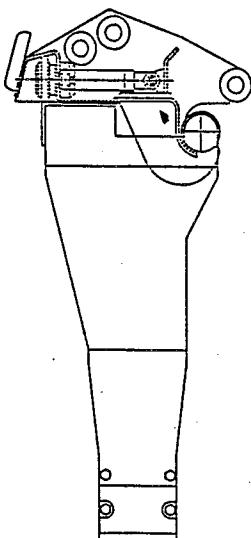


Figure A-1. Quick-Connect Coupler and Adapter on Hydraulic Hammer With Locking Pin Retracted

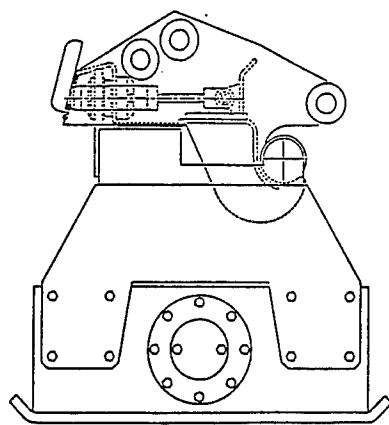


Figure A-2. Quick-Coupler Hitch and Adapter on Hydraulic Compactor With Locking Pin Extended

A double-acting hydraulic cylinder functions as the lock pin (Figure A-3). The rod end of this cylinder is pinned allowing the barrel to slide through the bosses in the hitch. The front boss acts as a pilot. Extension and retraction of the cylinder are, therefore, along a defined path and a chamfer on the cylinder end cap further assists in the alignment. Because of the relatively long stroke and short mounting space and the fact that the front of the barrel slides through the bosses, the extend porting is through the rod and rod end. The rod end bushing is a spherical ball-type. At 1500 psi the force to lock is 2,650 pounds and force to unlock is 1,473 pounds. These forces are greater than would have been available using either a pneumatic or electric solenoid actuator in the space allowed.

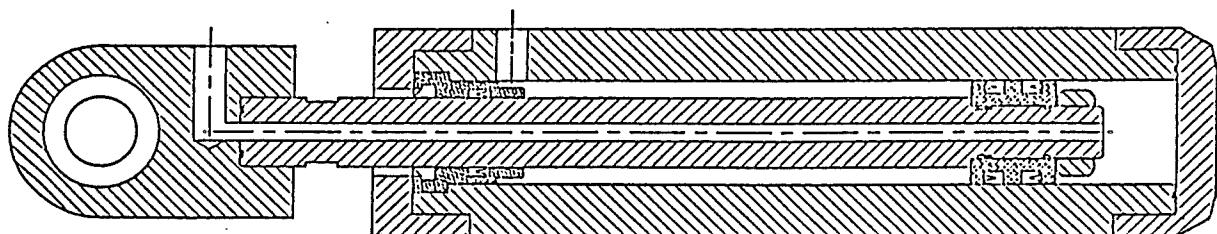


Figure A-3. Cross Section of Hydraulic Cylinder Used as Quick-Coupler Lock

A machined plate welded to the inner sides of the hitch supports the quick-connect bodies and their actuators in an exact position. Likewise, a machined plate spanning the inner sides of the adapter holds the quick-connect nipples at a corresponding position.

### 3. Developmental Testing

Two series of developmental tests were conducted. After the first tests in which some problem areas were identified, modifications were made, and additional tests were conducted.

#### a. Alignment of the Hitch

In its normal configuration, the quick coupler hitch is forced into alignment with the adapter by a tapered plate welded to the outside of each hook member (Figure A-4). These tapered plates bear against the inner walls of the adapter and guide the hook after it has started the rolling motion. The thickness of these plates above the taper provides a close fit with the adapter side plates and thereby prevents relative side-to-side motion, but only when the hitch is close to bottoming out on the adapter. Because the initial engagement of the hook was unguided and could be misaligned, the rolling hook could contact and damage the machined plates mounting the nipples in the adapters. To overcome this problem, an additional tapered plate was welded to the side of each hook to force easy alignment.

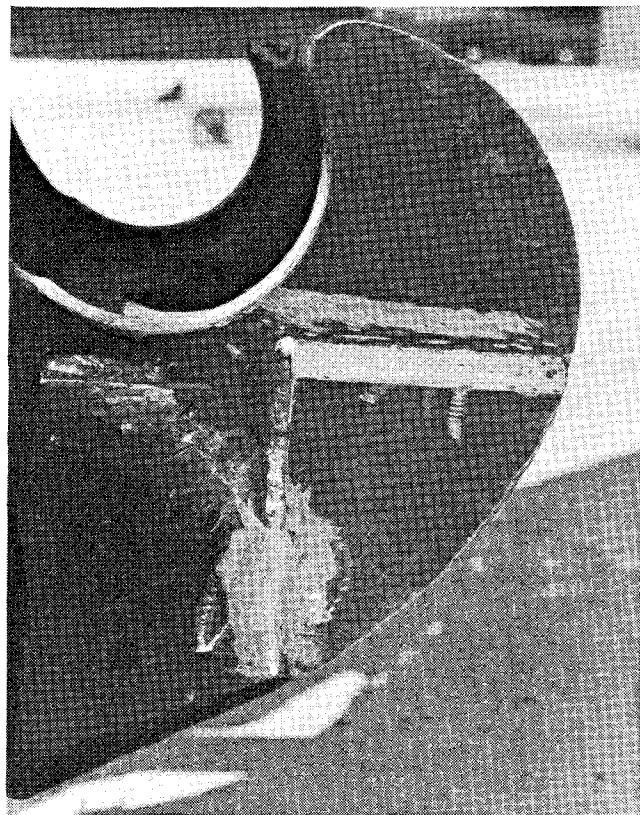


Figure A-4. Quick-Coupler Hitch Modified With Tapered Plate

### b. Hydraulic Cylinder

During the first series of tests, the barrel of the hydraulic cylinder rotated causing the hose to twist and bind. To prevent this undesirable rotation, an external longitudinal groove was machined in the barrel and a guide pin was fitted to the inner boss of the hitch (Figure A-5). This change was successful and neither the guide pin nor the groove showed wear.

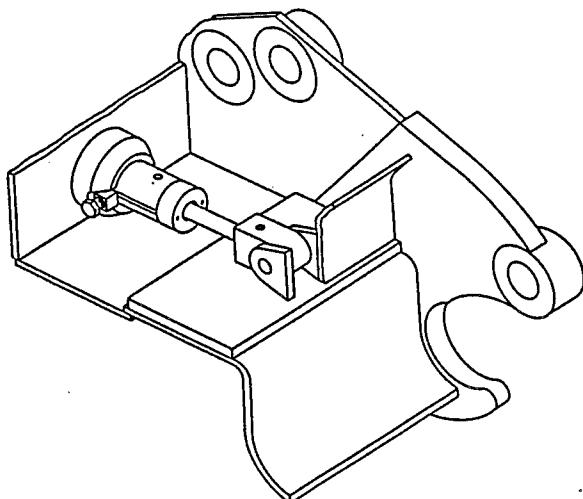


Figure A-5. Quick-Coupler Hitch With Modified Lock Pin

### c. Contamination Guard For Digging

The original design specified a channel-shaped weldment within the bucket to cover and guard the quick-connect components in the hitch which would otherwise be exposed in the bucket. This was both difficult to install and did not provide adequate protection. A redesigned guard in the bucket and a matching guard member in the hitch provided adequate protection. These are shown in Figure A-6.

### d. Hydraulic Subsystem

The first series of tests was conducted on the prototype RRR excavator, a John Deere 690B. The primary hydraulic system on this excavator is open center, but a closed-center pump had been added to operate certain nonstandard attachments. This close-center circuit was selected to provide hydraulic power to the Mechanized Quick-Connect System.

The later tests were conducted using a standard RRR excavator (a modified John Deer 690C). Because the hydraulics on this vehicle were open-center, there were certain problems in the adaptation. The open-center circuit controlling the action of the dozer blade matched the flow rate and pressure requirements for

the Mechanized Quick-Coupler System. With the addition of the correct sleeve and plug, the blade directional control valve is convertible to power beyond. After numerous unsuccessful attempts to secure the correct sleeve and plug, a closed-center Mechanized Quick-Connect System valve was plumbed in parallel with the blade lift circuit. Although this scheme met the pressure and flow requirements, it did require the blade lift control to be maintained in the bottomed-out position during actuation of the quick-connect valve. Two problems with this scheme were the time delay resulting from the operator having to first bottom out the blade lift function and the requirement that he simultaneously hold both the blade control lever and the quick-connect control switch.

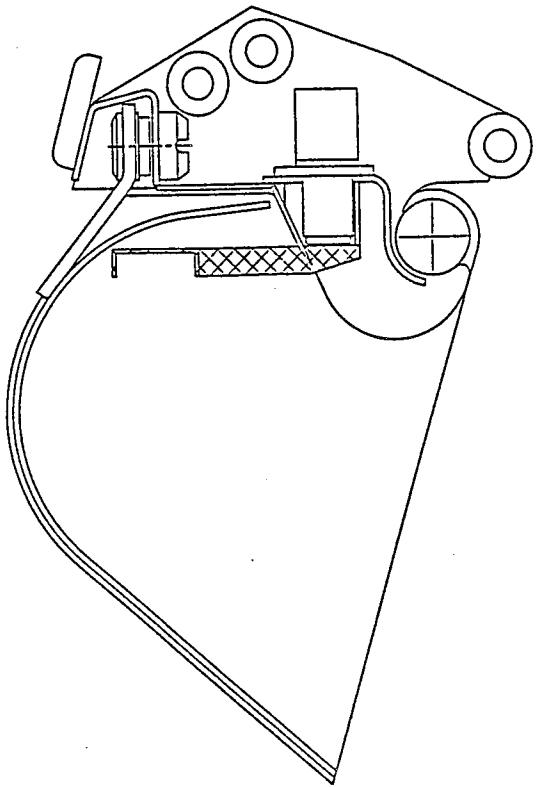


Figure A-6. Quick-Coupler Hitch and Bucket With Contamination Guards

#### 4. Field Test

A separate detailed field test report on the Mechanized Quick-Coupler System has been written (see Appendix C). Only a general overview of the field tests is described in this appendix.

##### a. Objective

The objective for the field test of the Quick-Coupler Subsystem was to measure the time required for tool-to-tool exchanges. A second objective was to determine the effectiveness of the contamination guard for digging.

### b. Test Description

The elapsed time required to complete an exchange of the attachment tools was measured. All possible combinations of tool exchanges were measured numerous times.

The quick-connect components which extend into the bucket were visually inspected for contamination and operated after digging.

### c. Results

Mechanically, the Quick-Coupler Subsystem performed very well during all field tests. However, the general result was that the tool exchange took slightly more than 1 minute. The operator difficulties caused by the abnormal hydraulic circuit contributed significantly to this greater elapsed time. After the modified bucket was used to dig a 10-foot by 10-foot by 5-foot excavation, visual inspection of the quick-connect components revealed very little contamination. During the excavation, the guard did not inhibit digging.

## 5. Conclusions

The test demonstrated that the quick-coupler locking mechanism is effective and easy to use. The time requirement defined in the SOW is reasonable and achievable.

## B. QUICK-CONNECT (HYDRAULIC) SUBSYSTEM DEVELOPMENT

### 1. Overview

A pair of standard quick-connects was used in conjunction with specially designed and manufactured actuators. Rubber boots covered the quick-connect bodies and nipples for contamination protection.

### 2. System Description

Two hydraulically controlled actuators shift the quick-connect bodies from a normal position behind rubber boots to an extended position and locking engagement with the quick-connect nipples (Figures A-7 and A-8). In the normal position, the nipples are protected by a pair of rubber boots, but these boots are retracted by the action of the actuators. To disconnect, the actuators unlock the quick-connects and retract the bodies back to the normal position. The face of each rubber boot is segmented by a series of radial cuts (Figure A-9). In the normal position, these segments form a closed flat face. When the segments are extended, they form a circular opening which allows a round component to pass through the boot. They are so constructed that upon withdrawal of the component, they resume their normal position and close.

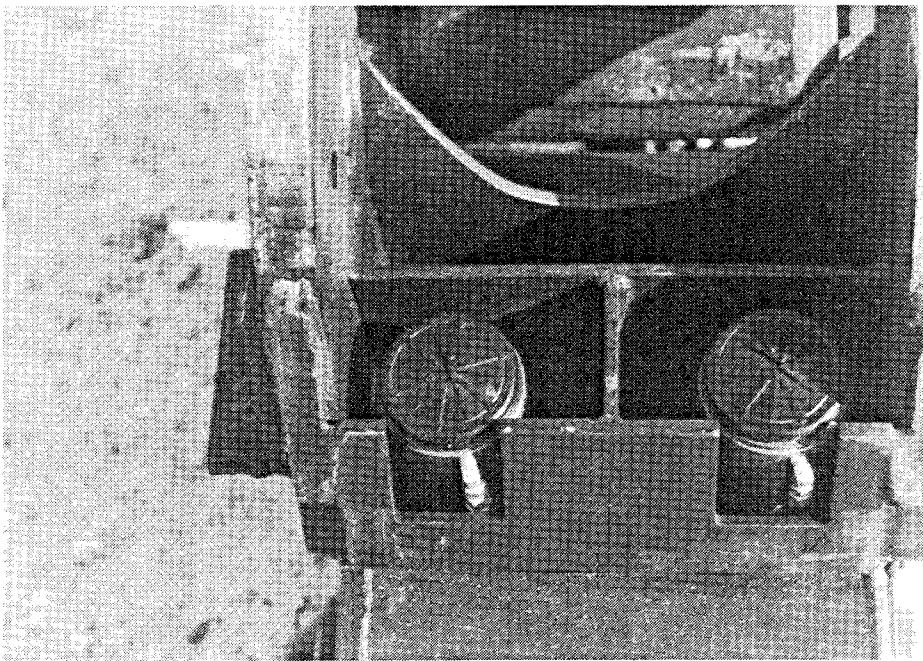


Figure A-7. Quick-Connect Actuators Mounted in Quick-Coupler Hitch

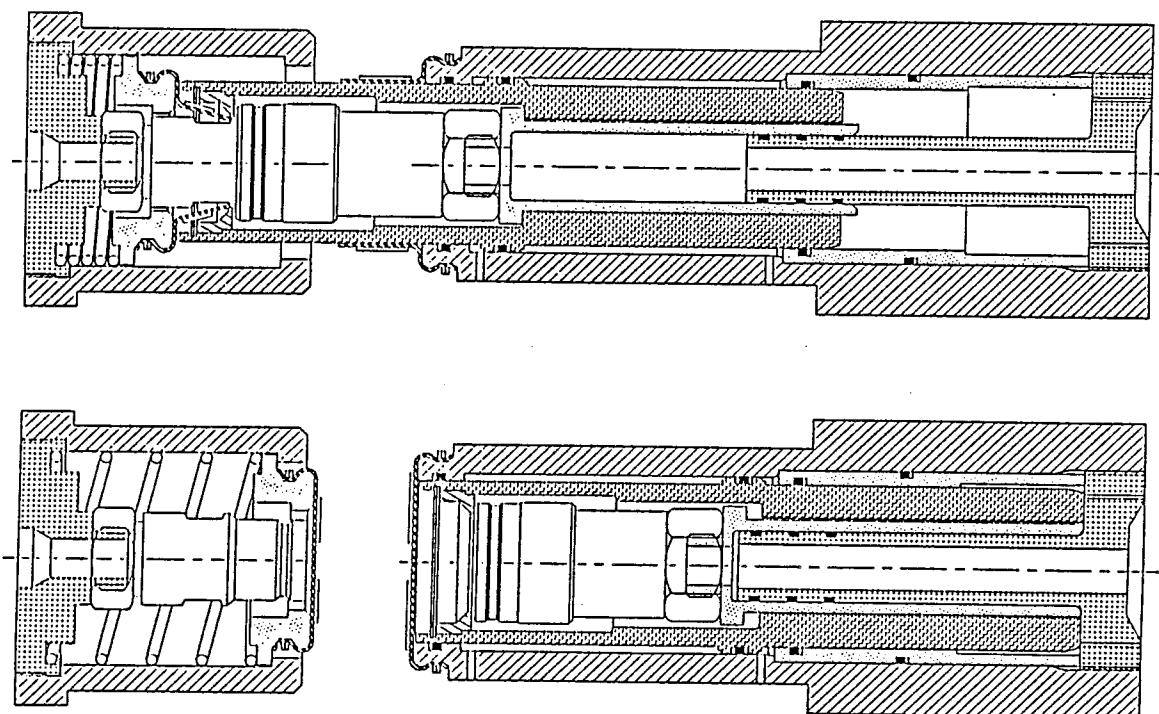


Figure A-8. Quick-Connect Cross Sections - Coupled and Uncoupled

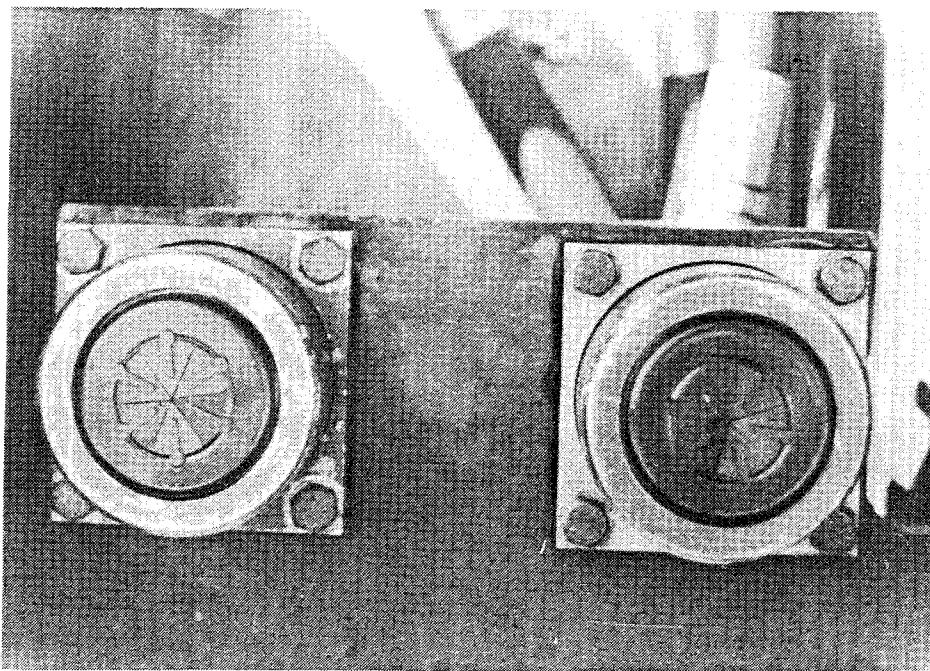


Figure A-9. Quick-Connect Nipple Housings With Protective Rubber Boot

### 3. Developmental Testing

#### a. Quick-Connects

The initial developmental tests revealed one serious problem with the quick-connects. Because of both the design of the hydraulic attachment tools and the design of the hydraulic circuit which powered them, the quick-connects could be under pressure at the time of disconnect. This condition repeatedly caused an O-ring seal in the nipple to blow out. This failure required replacement of those quick-connects. The replacement quick-connects were designed to both connect and disconnect while pressurized. At the same time, the actuators and the housings which mount the nipples were mounted on rubber pads to assist in alignment and reduce vibration between the quick-connect bodies and nipples. Each pad under the actuators was 3/8 inch thick and each pad under the nipple house was 1/2 inch thick. All pads were 60-durometer neoprene.

#### b. Actuators

The actuators performed well during all tests. The tests revealed three critical factors:

(1) Alignment of the quick-connect bodies with the nipples;

(2) Distance between the actuators and housings for the nipples when the quick coupler is locked; and

(3) Contamination in the working mechanisms of the actuators.

To assist proper alignment of the quick-connect components, a taper was machined on the outside diameter of the nipple. This was effective.

To obtain the proper distance between the actuators and the nipple housings, the capscrews mounting the actuators and the nipple housings were adjusted to compress the vibration dampening rubber pads. Once the proper spacing was obtained, there was no need for readjustment during the test period. Removal of the actuators during the test period revealed no plastic deformation of the rubber pads.

A failure of the contamination protection boot on the actuator did introduce gross contamination into the actuator mechanism requiring disassembly and realignment of the actuator.

#### c. Contamination Protection

Protective rubber boots covered both the actuators and the nipple housings. During the first series of developmental tests, it was determined that the boot segments were not closing fast enough. A redesign of the boot provided a rib on each segment to both add stiffness and to function as a spring causing quicker closure. This modification was effective in later tests, but the boots did not prove to be adequate for protection from contamination.

### 4. Field Tests

#### a. Objective

The two objectives for the field tests of the Quick-Connect Subsystem were: (1) to determine the capability of the hydraulic quick-connects to function properly after extended uses on both the hydraulic hammer and the hydraulic compactor, and (2) to determine the effectiveness of the contamination protection system.

#### b. Test Description

The test was designed to operate both the hydraulic hammer and the hydraulic compactor for periods of 3 hours each without a sustained hydraulic leak in the quick-connects. To test the effectiveness of the contamination boots, the actuators with the boots attached and the nipple housings with the boots attached were submerged in contaminants as shown in Figure A-10. After the contaminants were brushed off, the quick-connects were actuated to lock and unlock a number of times.

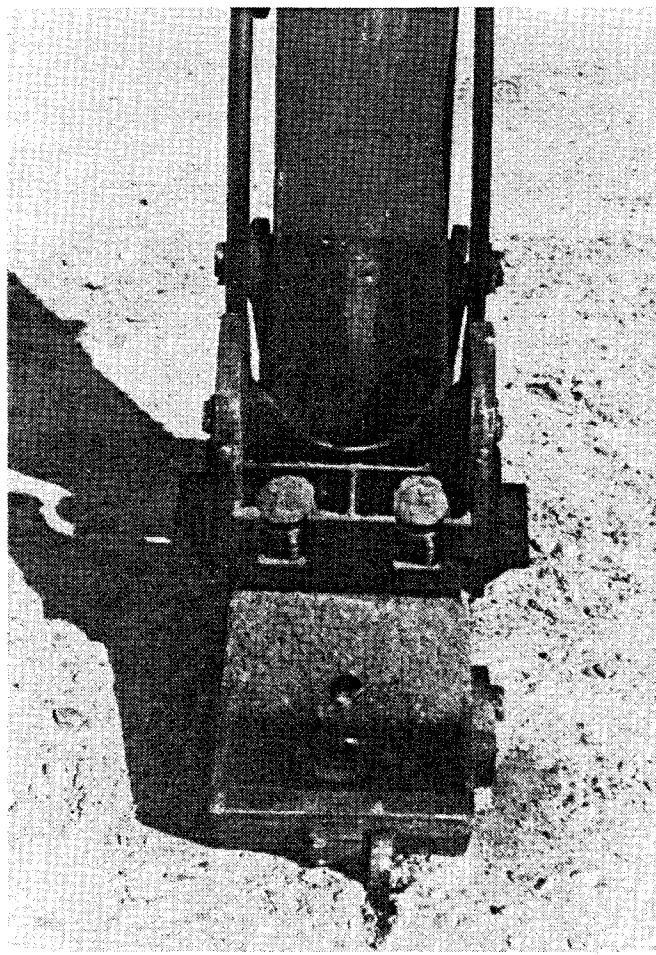


Figure A-10. Quick-Connect Actuators During Contamination Test Before Excess Contamination Was Brushed Away

#### c. Results

During and after the extended operation of the hydraulic compactor, no detrimental effect was observed. However, during the extended operation of the hydraulic hammer, a major hydraulic blowout occurred. The quick-connects were disassembled, inspected, reassembled and placed back into service without further leakage, although the test was concluded early because of an excavator problem.

The test of the effectiveness of the contamination boots resulted in contamination of the quick-coupler lock mechanism and a failure of a hydraulic seal in the quick-connect.

#### d. Conclusions

Inspection after the blowout revealed that the quick-connect body, the nipple, and the actuator appeared to be undamaged; therefore, the cause of the blowout can be attributed to failure of the quick-connect body and nipple to lock together.

This was probably due to an inaccurate adjustment of the distance separating the actuator and the nipple housing.

The failure of the contamination boots indicates the ineffectiveness of that specific boot design.

### C. CARRYING DEVICE DEVELOPMENT

#### 1. Overview

The carrying device was a structural steel tray with an integral adapter. The field tests pinpointed certain deficiencies, but proved the effectiveness of the concept.

#### 2. Description

The carrying device consisted of two weldments of primarily structural steel channel bolted together at the test site. This two-piece design was required because of shipping size limitations. For the safety considerations, the carrying device retains each attachment tool as well as the hammer tamping pad and the alternate moil, frost spade and chisel hammer tools in a definite position. It is designed so that the hammer, with any of its tools will fit onto the tray (Figure A-11). Therefore, it is not necessary to remove the hammer tool, such as the tamping pad, to place the hammer on the carrying device.



Figure A-11. Carrying Device with Tools

The carrying device also contained a quick-coupler adapter for lifting and positioning. With a full complement of attachment tools, the carrying device was balanced about this adapter, thereby, imposing a minimum moment load on the excavator boom.

As shown in Figure A-12, the layout of the carrying device and its adapter is such that the rearward or bucket support section can be supported by the excavator dozer blade for transport. This further reduced the strain on the boom.

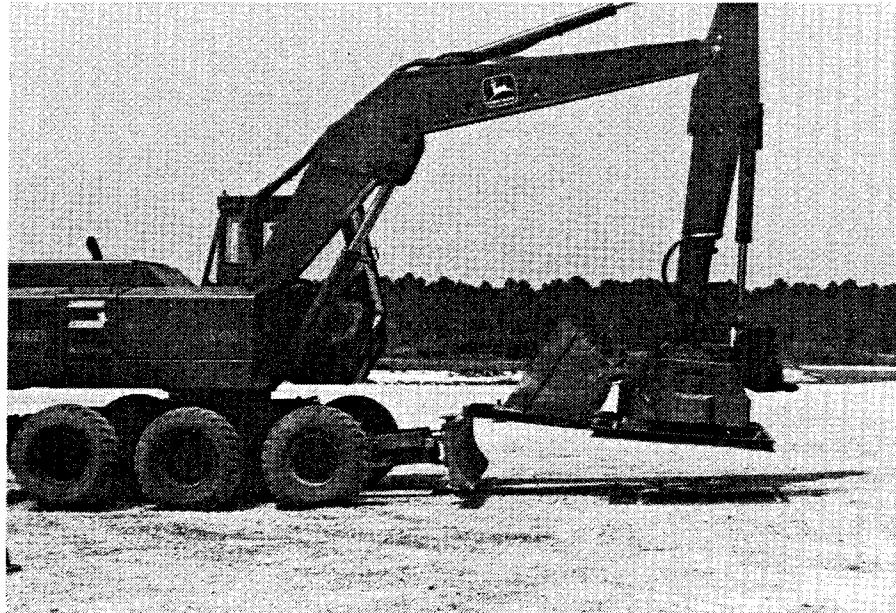


Figure A-12. Carrying Device in Transport Position

### 3. Developmental Testing

The carrying device was tested during both series of tests. During the first tests, two problems were identified. First, there was excessive deflection in the bolted joint between the bucket support section and the remainder of the tray. This joint was welded after the first test and showed noticeable improvement in the later test. The second problem was the parallel orientation of the attachment tools. Because the quick-coupler needs head-on alignment, the parallel orientation of the attachment tools required that, after placing one tool on the carrying device, the operator had to move the excavator in order to pick up another tool. The correction of this problem required such a major modification to the carrying tray that it was not undertaken.

### 4. Field Tests

#### a. Objective

The three objectives of the carrying device field test were to determine the time required to pick up and position, for transport, a fully loaded carrying device, to test the stability and the tool retention of the carrying device during transport, and to evaluate the stability of the excavator while carrying a fully loaded tool-carrying device on both level and sloped surfaces.

b. Time Limit

A goal of 2 minutes was set for the test which consisted of removing an attachment tool from the hitch, placing it onto the carrying device, picking up the carrying device and moving it into the transport position. The goals of the other two tests were to transport a fully loaded carrying device at rated speed and gradability.

c. Results

The carrying device performed well with these exceptions. If the orientation of the tools were radial rather than parallel, the times required for tool exchanges and for picking up the carrying device would have been improved significantly. Also, the hydraulic hammer was supported near its center of gravity and had a tendency to tumble forward. In addition, the hammer was positioned almost horizontally with the hitch on the side away from the operator. This made positioning the hitch more difficult.

The test of the carrying device demonstrated that is a workable, efficient means for transporting a full set of attachment tools and the alternate hammer tools. Although the two problems encountered would require considerable modification of the carrying device, the manufacture of a new carrying device could incorporate the modifications without consequence.

#### SECTION IV

#### CONCLUSION

The Quick-Coupler System has been designed, manufactured and tested. In spite of certain problems which arose during testing, the system successfully demonstrated the feasibility of the remote Quick-Coupler System. The contamination protection means requires considerable redesign. If this were improved, the Mechanized Quick-Connect System would be a safe, efficient, and reliable addition to the RRR operation.

APPENDIX B\*

DESIGN "B" QUICK-CONNECT SYSTEM

Dick T. Atkinson  
Robert Kleinhans  
Joseph Spector

Foster-Miller, Inc.  
350 Second Avenue  
Waltham, MA 02254

\* The material in this appendix is being published in the same format as submitted by the contractor

## SECTION I

### INTRODUCTION

Repair of bomb-damaged runways is an operation which must be accomplished quickly and with a resultant quality which will support resumed aircraft operations. The Air Force is supporting runway repair through a program entitled Rapid Runway Repair (RRR). In earlier work, new materials, equipment and techniques have been, and continue to be, developed towards achieving the RRR objectives. More reliance has been given to mechanized equipment because of factors such as achieving the desired repair time regardless of weather conditions and allowing personnel to carry out a task without leaving the protected equipment cabs.

The objective of this contract is to provide a system which will allow the multipurpose excavator operator to quickly change tools to the boom of the excavator. Tool-changing will include making an automatic hydraulic connection, where appropriate, in addition to making the mechanical connection. The tool-to-tool change must be made within 1 minute and must be accomplished without any degradation in excavator performance. Both the mechanical and hydraulic connections are to be environmentally protected from contaminants such as rock, sand, clay, ice, and hydraulic fluids.

In addition, a carrying device for the tools is needed such that the excavator will be able to transport the bucket, hydraulic hammer and hydraulic compactor plate to and from the work site. The tools are to be arranged in such a way as to facilitate easy and quick tool-to-tool change.

Section II will describe the design, fabrication, and testing of the mechanized quick-connect system.

The program conclusions will be described in Section III.

## SECTION II

### SYSTEM DESIGN

The discussion of the program is broken down into five areas. They are:

- The toggle-action mechanical coupler (TAC).
- The hydraulic quick-disconnect/swivel.
- The tool-carrying device.
- Fabrication and assembly tasks.
- Testing at Tyndall Air Force Base.

The remainder of this section will be dedicated to describing hardware design, the fabrication and assembly tasks, and the testing at Tyndall AFB.

#### A. THE TOGGLE ACTION MECHANICAL COUPLER

The basic concept development used for this system was designed around a prototype system that had previously been built and tested by the Caterpillar Tractor Company (CAT). Their prototype was built on a J.I. Case 580C loader/backhoe and the system was subsequently tested in both digging and hammer operations. The encouraging results of these tests were the basis for the toggle action mechanized coupler that was designed in this program.

CAT's original concept was modified to adapt it to the USAF-owned John Deere 690C excavator. Figure B-1 shows the end of the stick in its purchased condition.

The challenge was to design the mechanism with minimal, if any, modifications of the existing boom, stick, links, and curl cylinder. An initial geometry investigation was used to

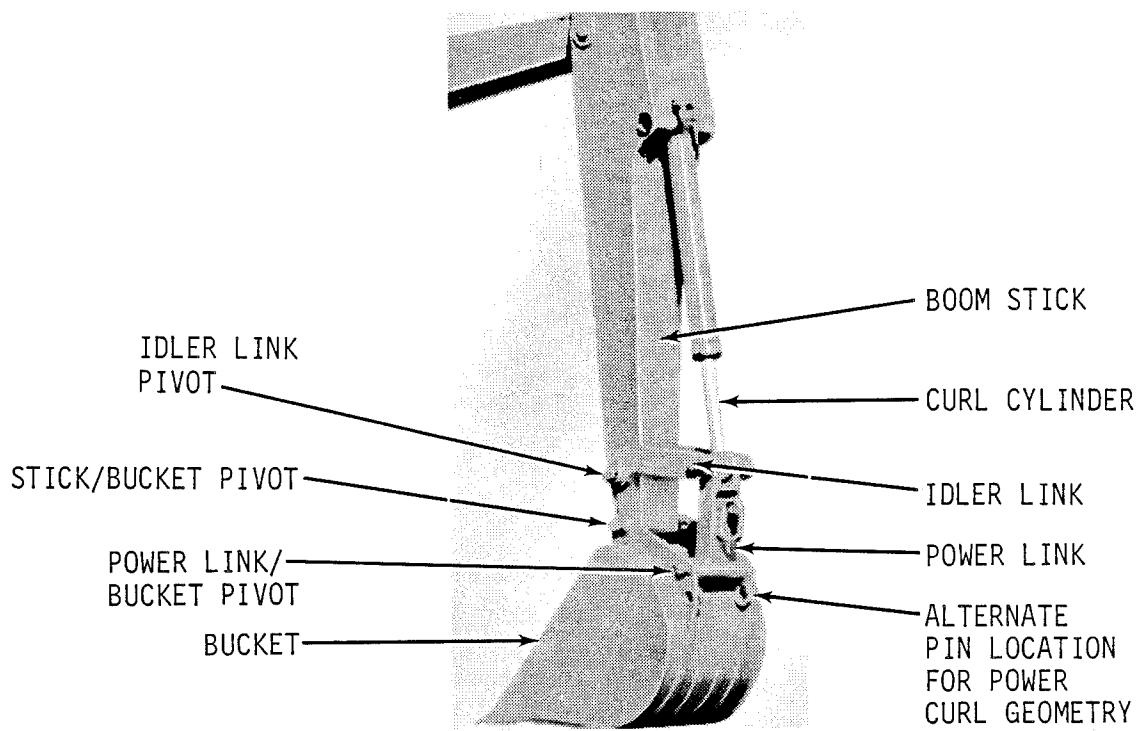


Figure B-1. Standard John Deere 690C Bucket/Linkage.

investigate the interaction of the linkages in the various configurations that occur during the latching/unlatching operations. See Figure B-2. A cardboard scale model revealed two problems: linkage jamming and the length ratio of the toggle linkage.

In Figure B-2(a), the mechanism tends to jam when the center points 1, 2, and 3 are on a straight line or when point 2 is to the left of a line connecting points 1 and 3. Subsequent discussions with CAT and an analysis of the problem indicated that the same problem could occur on the J.I. Case 580C loader/backhoe under certain conditions and, although we were fairly confident in the operator's ability to avoid this geometry, we could not guarantee it. One scenario for solving the problem was to beef up the locking pin (not shown in Figure B-2) which snaps into place when the linkages are in the configuration shown in Figure B-2(d). However, if

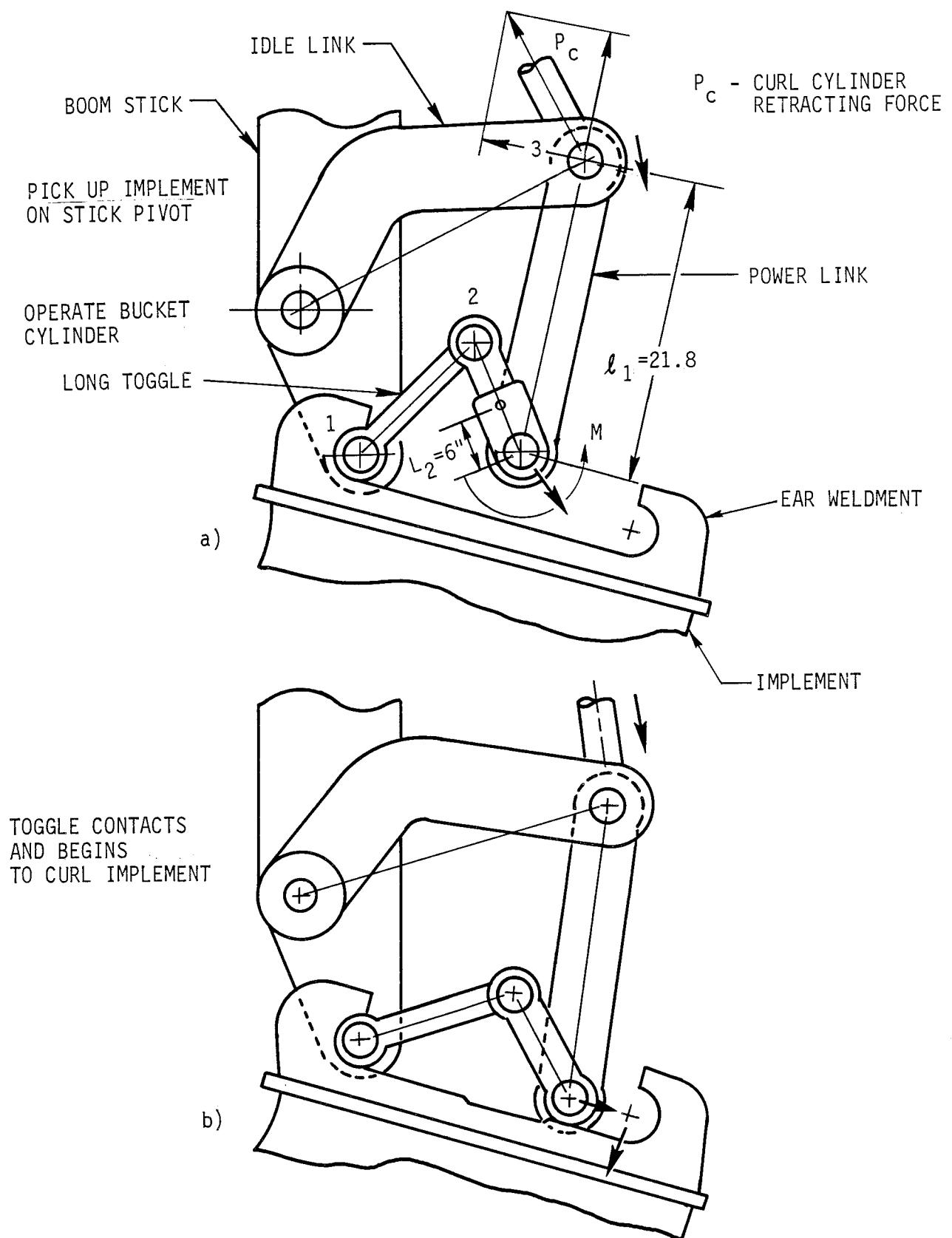
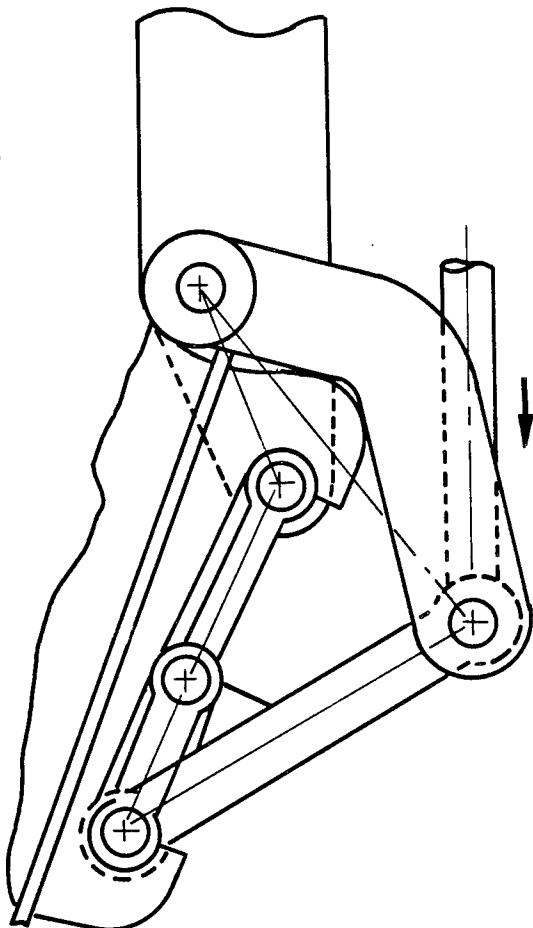


Figure B-2. TAC Concept in a John Deere 690C Geometry.

TOGGLE DRIVEN  
OVERCENTER AT  
MAX CURL

c)



BUCKET CYLINDER  
UNCURLS IMPLEMENT

NORMAL EOM  
OPERATING  
GEOMETRY

TOGGLE IS TIGHT

d)

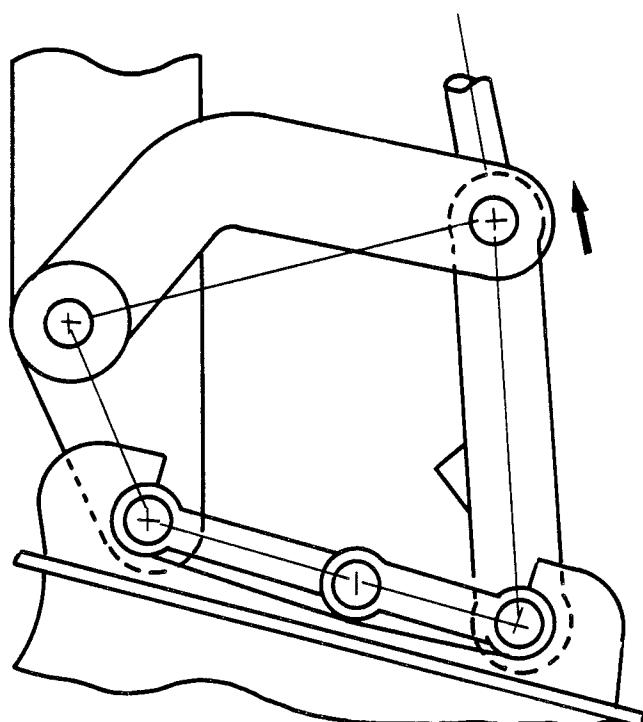


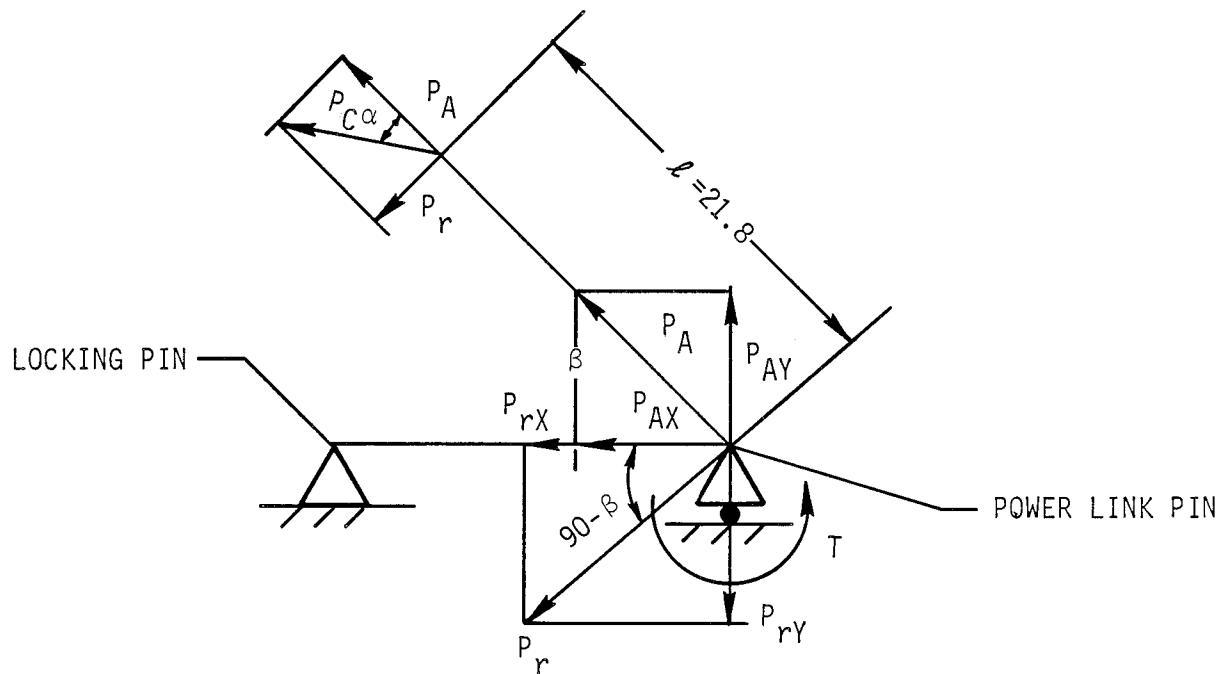
Figure B-2. TAC Concept in a John Deere 690C Geometry (concluded)

this were the case, the locking pin might have to withstand the full force of the curl cylinder. A free-body diagram indicated the total force could approach 47,650 pounds on each of the two locking pins. This analysis is shown below:

$$P_C = p \cdot \frac{\pi}{4} (D^2 - d^2) = 3000 \cdot \frac{\pi}{4} (5.5^2 - 3.25^2) = 4,640$$

$$P_A = P_C \cos\alpha = 46,400 \cdot \cos 30^\circ = 40,200 \text{ lb}$$

$$P_r = P_a \cdot \sin\alpha = 46,400 \cdot \sin 30^\circ = 23,200 \text{ lb}$$



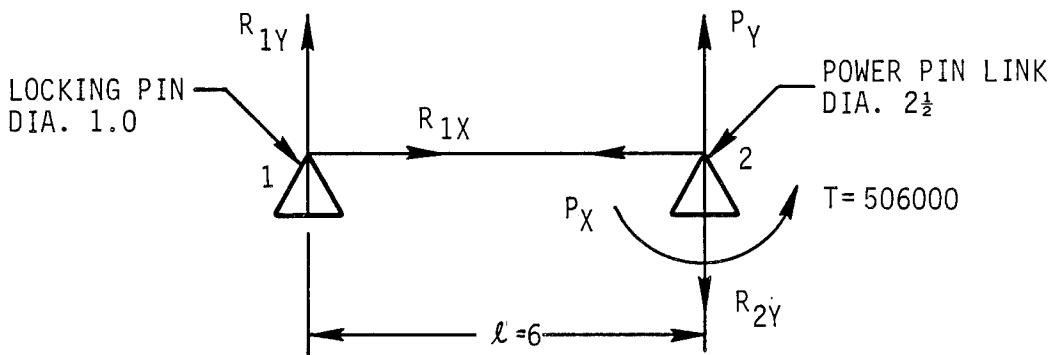
$$P_X = P_{rX} + P_{AX} = P_A \cos\beta + P_r \cos(90^\circ - \beta) =$$

$$P_A \cos\beta + P_r \sin\beta = 40,200 \cdot 0.70 + 23,200 \cdot 0.7 = 444$$

$$P_Y = P_{AY} - P_{rY} = P_A \sin\beta - P_r \cos\beta =$$

$$40,200 . 0.7 - 23,200 . 0.7 = 11,900 \text{ lb}$$

$$T = P_r \cdot \ell = 23,200 . 21.8 = 506,000 \text{ in. lb}$$



$$\Sigma M(1) = -P_Y \cdot \ell + R_{2Y}\ell - T = 0$$

$$R_{2Y} = \frac{P_Y \ell + T}{\ell} = \frac{11,900 . 6 + 506,000}{6} = 96,233$$

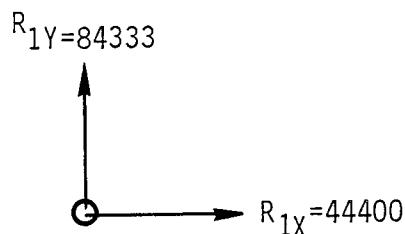
$$\Sigma M(2) = + R_{1Y}\ell - T = 0$$

$$R_{1Y} = \frac{T}{\ell} = \frac{506,000}{6} = 84,333 \text{ lb}$$

$$\Sigma Y = R_{1Y} + P_Y - R_{2Y} = 84,333 + 11,900 - 96,233 = 0$$

$$\Sigma X = P_X = R_{1X} = 44,400 \text{ lb}$$

Locking pin loads (resultant)

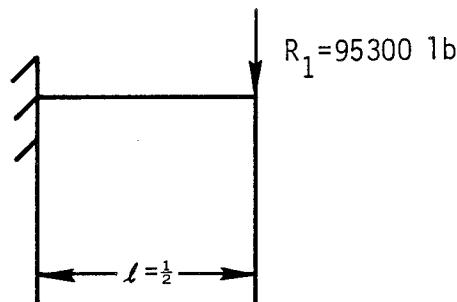


$$R_1 = \sqrt{R_{1Y}^2 + R_{1X}^2} = \sqrt{84,300^2 + 44,400^2} = 95,300 \text{ lb}$$

Power link pin

$$R_2 = \sqrt{(P_{2Y} - P_Y)^2 + P_X^2} = \sqrt{(96,233 - 11,900)^2 + 44,400^2} = 95,300 \text{ lb}$$

Locking pin strength (1 in. diam)



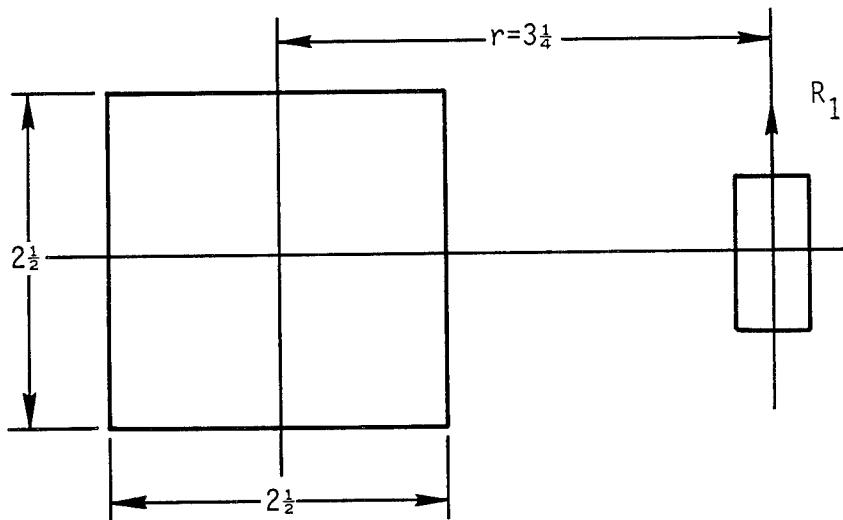
$$M = R_1 l = 95,300 \cdot 0.5 = 47,650 \text{ in. lb}$$

$$f_b = \frac{M}{S} = \frac{47,650}{0.1 \cdot 1^3} = 476,500 \text{ psi} \gg f_Y$$

If pin is 2 in. dia

$$f_B = \frac{M}{S} = \frac{47,650}{0.1 \cdot 2^3} = 59,600 \text{ psi}$$

If the pin holds the jamming load, the torsional stress will be included in the toggle links.



$$T = R_1 \cdot r = 95,300 \cdot 3 = 309,700 \text{ in. lb}$$

$$f_T = \frac{T}{S} = \frac{309,700}{0.208 \cdot 2.5^3} = 95,300 > f_{T2}$$

The sizes of links will have to be increased along with other changes to beef up the design.

A modified design solved the problem with the addition of two powerful torsion springs. The torsion springs and locking pin are shown in the assembly drawing in Figure B-3. The torsion springs prevent the in-line link configuration and the sole function of the locking pin is to prevent the linkage from snapping back overcenter. This simplified locking pin design replaced the twin locking pins originally proposed. Those pins

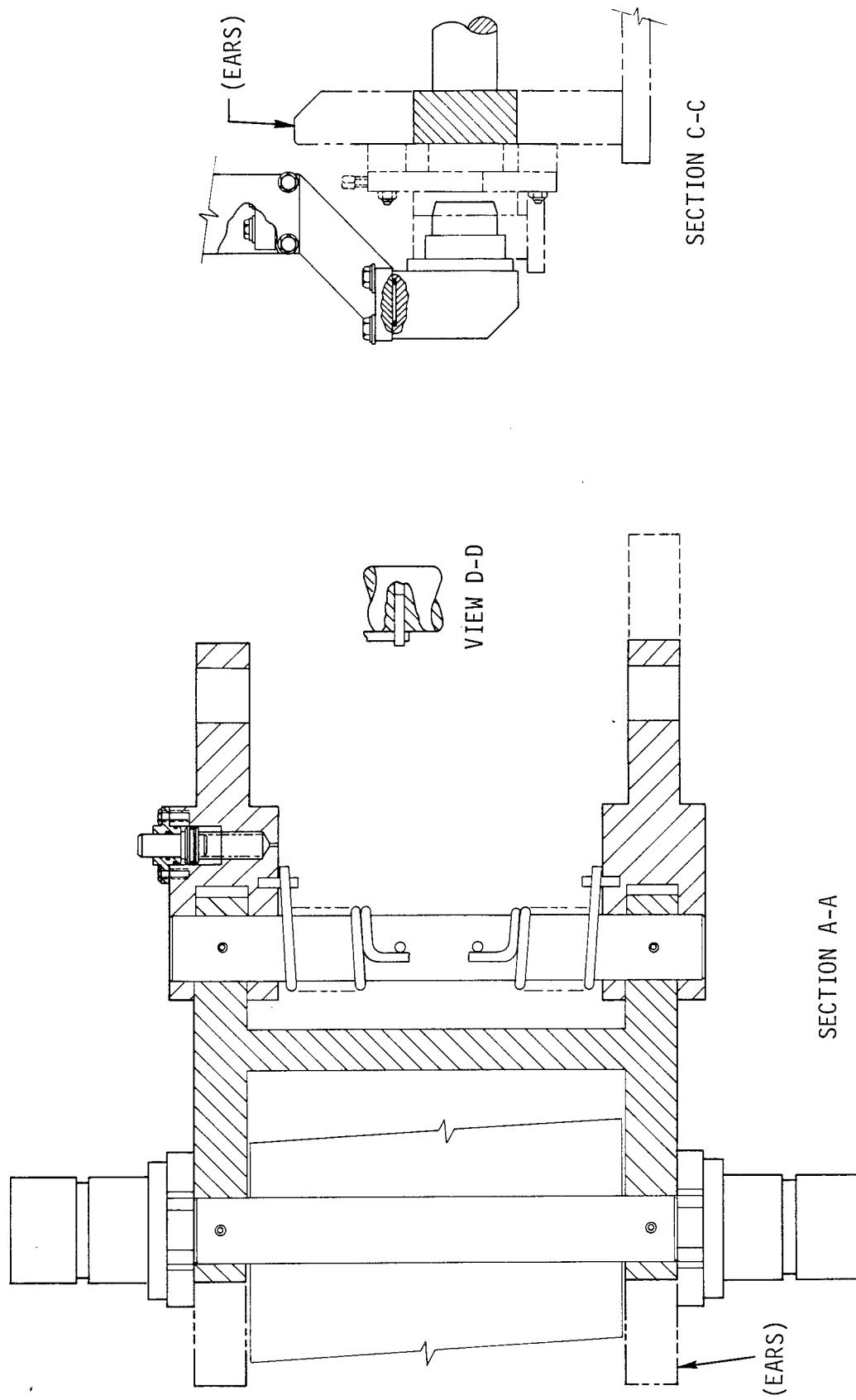


Figure B-3. TAC Assembly (Plan View).

acted as two-way cylinders, as shown in Figure B-4. The new design is a simpler spring-engaged, hydraulically released cylinder. An additional benefit derived from this design was much simpler plumbing.

The second problem, that of an incorrect length ratio of the toggle linkage, was also discovered by exercising the scale model. At certain ratios between the long and short toggle lengths the curl cylinder travel is insufficient to complete full engagement of the mechanism. After some fine-tuning, an optimal ratio was obtained which left a 4-inch stroke in the curl cylinder after the toggle was fully engaged (driven overcenter) as depicted in Figure B-2(c).

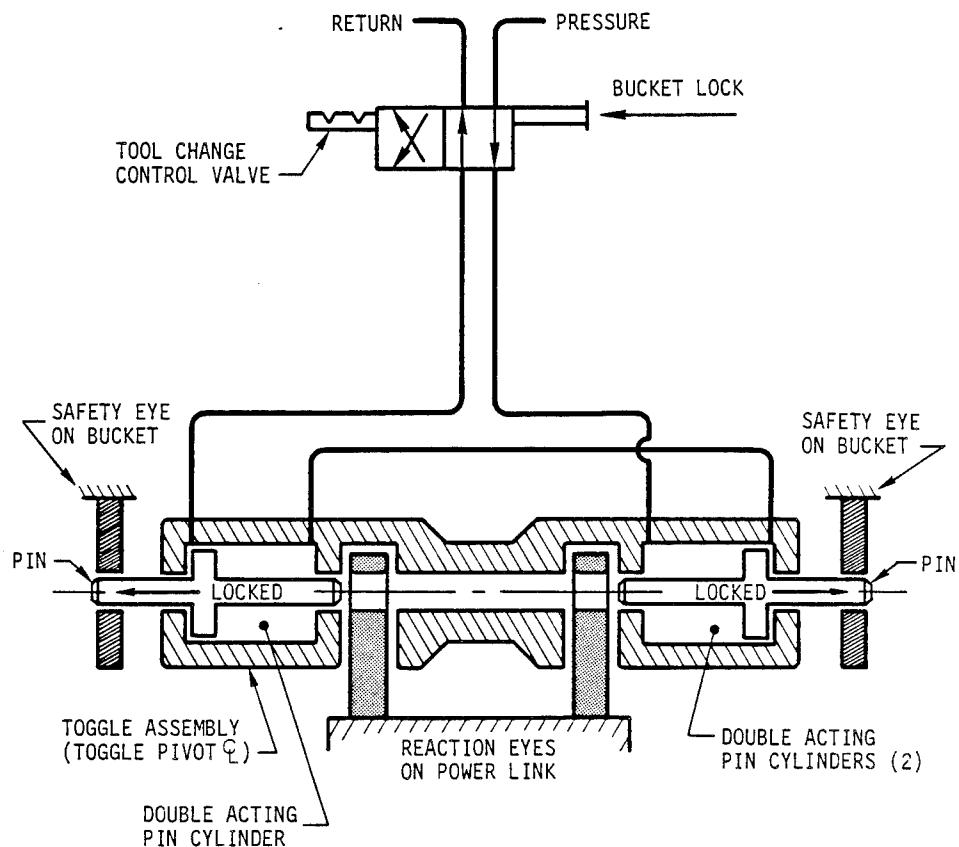


Figure B-4. A Cross Section through the Toggle Pivot Centerline.

The toggle mechanism attaches the boom stick to each of the tools through the use of common sets of ears. (See Figure B-5.) Figure B-6 shows the toggle mechanism totally engaged in the ears. The toggle ears are two, 2-inch (50 mm) thick flat bars welded to a common plate. The configuration of the ears is determined by the toggle link geometry as defined earlier in this section. The front ears (those at the top) have chamfers to facilitate easier engagement with the toggle links located on the excavator stick. A bracket welded to the side on one of the ears has a hole for the reaction pin. Both ears are welded to a common 1-inch (25 mm) plate which is, in turn, welded to a tool: bucket hammer, compactor and also to the tool carrier. All implements were modified to accommodate the ear weldment. This approach allowed us to make four identical ear weldments which simplified manufacturing of the system.

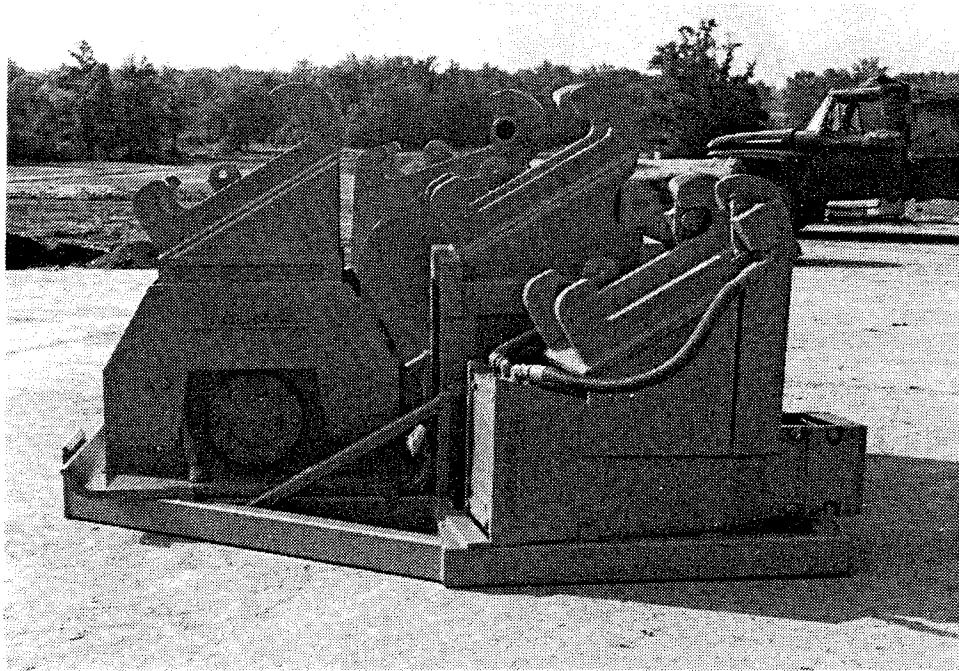


Figure B-5. Tools with Attachment Ears.

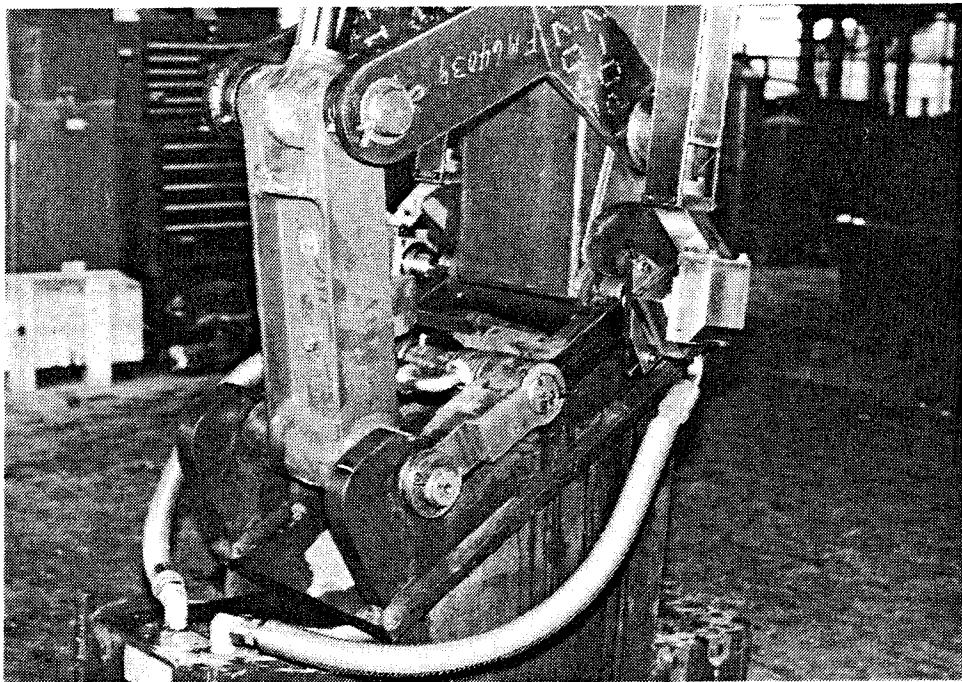


Figure B-6. Toggle Mechanism Totally Engaged in Ears.

#### B. THE HYDRAULIC SWIVEL/QUICK-CONNECT

As discussed earlier, the program requires that the excavator tools be remotely attached (or disconnected) to the excavator stick. The hydraulic power for the tools (bucket requires no hydraulics) requires supply and return lines at 3,000 psi with a minimum clear flow section equal to 1-inch diameter (0.78 square inch). The original design was conceived during the generation of the proposal. The design, shown in Figure B-7, outlines the conditions and puts forth an arrangement for a face seal quick-disconnect. This concept utilized an air plenum chamfer to provide cleaning action just before making the seals.

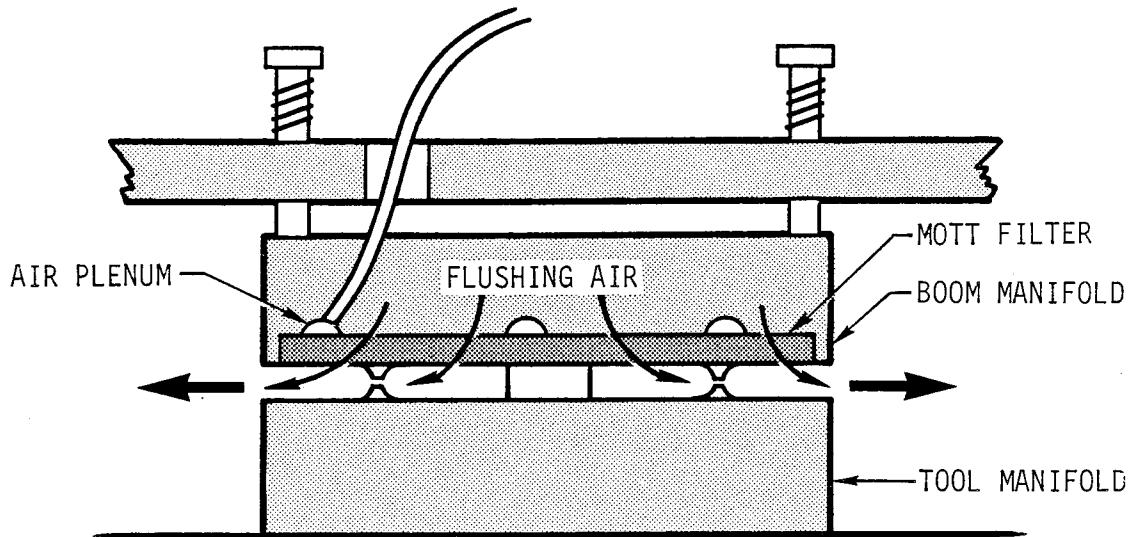


Figure B-7. Air-Cleaning System and Filter Plate for Face Seal.

Upon more detailed analysis it was found that the commercially available components (poppet valves, die sets) absorbed more space than could be tolerated in the available location. The idea of using air as a cleaning medium was rejected because it was felt to be inadequate for clay or ice contamination.

A design of a modified face seal arrangement was worked out in considerable detail. A quick-disconnect, using a protruding male half that engages a through-hole mating half was designed. The through-hole concept provided a unique method of cleaning the mating surfaces through the motion of the connecting operation. Although metal blocks still come together when connected, the faces are no longer the sealing surfaces. The sealing surfaces are the outer diameter of the male piston and the inner diameter of the female block. Sand

or dirt which may accumulate on the parts is pushed through the hole by means of a wiper on the piston, and exits through the bottom of the hole.

Scale models of this device were made to demonstrate the feasibility. Female blocks were resiliently mounted on the top surface of each tool and a pivoted male portion became part of the toggle link on the excavator stick. Commercial seals, O-rings, and back-up rings comprised the hydraulic seals. An advantage to this type of quick-disconnect was that it did not swivel. A small hydraulic cylinder was required to assist engagement. Location of the quick-connect, while limited in space, was within the confines of the toggle linkage, which affected a protected area.

Consultation with Caterpillar engineers resulted in not pursuing the through-the-hole design any further. Caterpillar had successfully built and tested a rotary seal unit utilizing recent developments in seals and bearings. The unit was successfully tested to one million cycles. A prototype of this concept was observed and the decision was made to use this type of seal even though the concept had not been designed for axial mating.

Another basic change was to relocate the two quick-connects to the axis of the lateral pin at the end of the excavator stick. This axis coincides with one end of the toggle and is the axis about which the tools pivot when in use. This is a logical location because it eliminates the need for hoses to accommodate tool pivoting. Less advantageous was the need to locate the quick-connects outboard of the toggle ears on each side of the tools. This poses no great problem on the hydraulic tools, but on an excavating bucket such protrusions outside of the bucket width prevent the bucket from entering a deep trench. This location would also require guards over the couplers to avoid having them damaged when the side of the boom

strikes a solid object. The outside width of the toggle ears is fixed and this is wider than a narrow bucket (24-inch) but presents no interference on a wide (48-inch) bucket. When designing the quick-connect system, much attention was devoted to permitting use of a medium (30-inch) rock bucket. Ironically, buckets do not need a hydraulic connection, but the excavator male half of the quick-connect is there anyway. Some advantage was taken of the fact that hydraulics are not used with buckets, by designing a dummy receptacle for the male disconnects in such a manner that the outside extreme width between the quick-connects when in use is less on buckets than on other tools. The resulting designs for the male and female halves of the quick-connect are shown in Figures B-8 and B-9, respectively. It was not possible to retain the self-cleaning feature of the feed-through design but the concept of having hydraulic flow introduced radially to both quick-connect members was retained. This serves to minimize resultant forces of pressure and flow, which tend to separate the connector halves. Both halves are sealed, when disconnected, by sliding sleeve members which also seal radially and cancel out forces due to pressure which would force the seal open. When connected, there is only a minimal area, upon which hydraulic pressure is exerted.

When the male half enters the mating half, several things happen:

- The nose of the male pushes in a sliding sealing cup in the female, which has engaged the seals. The nose and sealing sleeve on the male now engage the same seals that the cup had contacted.

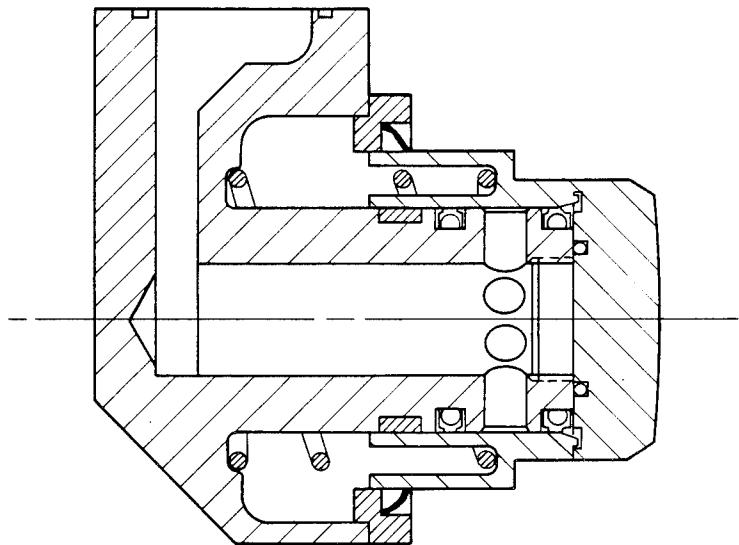


Figure B-8. Cross Section View of Male Coupler.

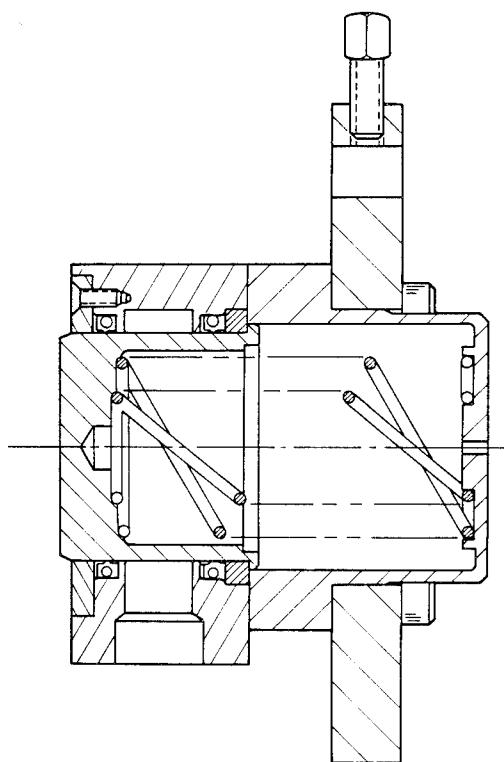


Figure B-9. Cross Section View of Female Coupler.

- When partially engaged in the female portion, a step on the male sealing sleeve contacts the face of the female quick-connect. This causes that sleeve to retract back, exposing radial flow ports on the inner portion of the male.
- Both the cup and the sealing sleeve are now repositioned to expose the ports in both halves, through-flow commences.

The sliding members of the quick-connect are spring-loaded in the closed position until the two halves mate. The hydraulic cylinders which pull the tubes in and engage the halves, must apply sufficient force to overcome the springs.

To summarize, the considerations which affected the design include:

- Ease and reliability of remote operation.
- The need to meet pressure and flow specifications.
- Minimum distance between backs of quick-connects.
- The need to minimize tendency of pressure to disengage the two halves.

Pressure and return lines run through the boom and stick of the John Deere excavator. These lines are connected to long tubes which solidly fasten to each of the two male quick-connect halves. The tubes run up along each side of the stick (see Figure B-10). The male/female connection is located at the bottom end of the tube as shown in Figure B-11. All static connections to the quick-connect and tubing are O-ring type seals. Each hydraulic tool has two female quick-connect

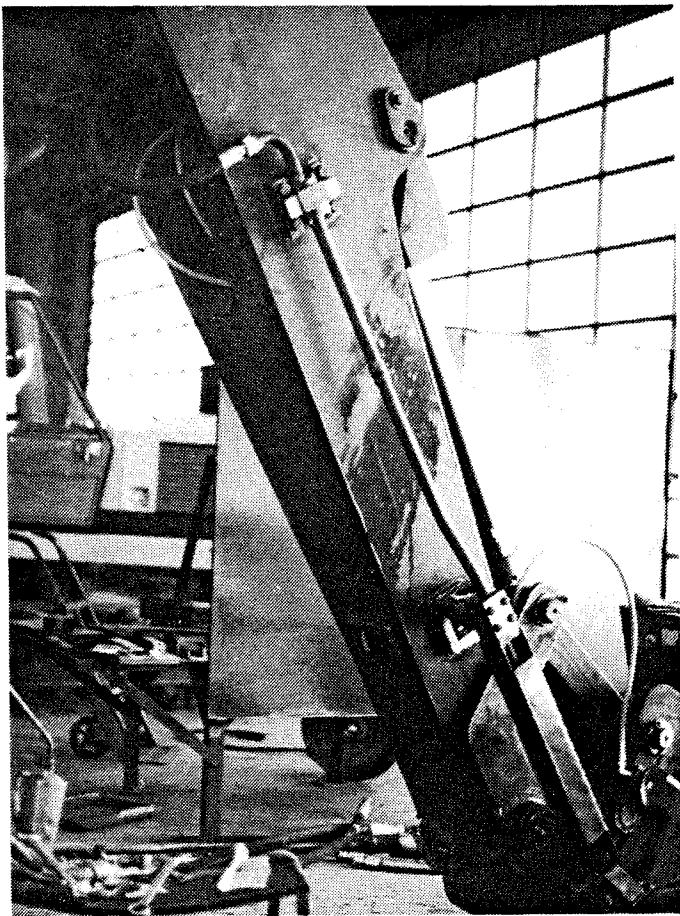


Figure B-10. Hydraulic Tubes on Excavator Stick.

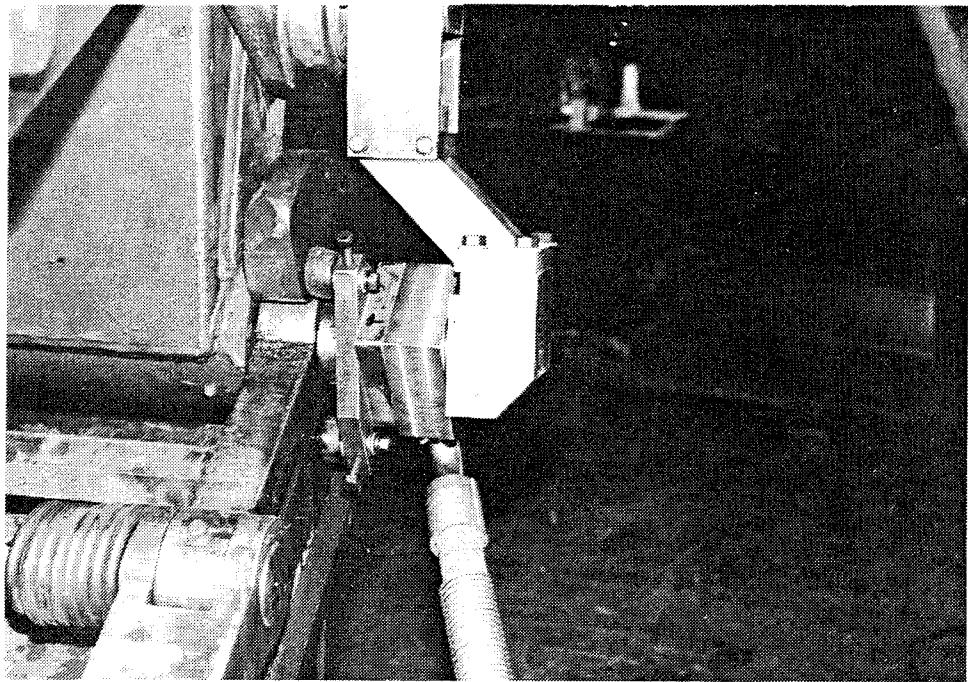


Figure B-11. Male/Female Connection at Bottom of Hydraulic Tubes.

halves attached to it. The mechanical connections are resilient rubber shock mounts to permit engagement and to accommodate any misalignment. The hydraulic connection from the female half to the tool ports are via hose and O-ring type connections.

The top of each 1.25-inch diameter steel tube is connected to a pivot adapter. This serves two functions:

- As a pivot to permit the tubes and male quick-connects to swing in or out.
- As an adapter to connect the hose to the tubes and to provide required resiliency to swing at the pivot.

Trunnion blocks which hold the pivot adapter are fastened to the stick by means of large cap screws. The long length of the pivoting tubes results in an arc, through which the male quick-connects travel, to approach a straight line. The small change in angle and effective length of the arm is compensated for by mounting the female halves resiliently. At assembly the quick-connects are mated and the pivot block adjusted, tightened and pinned to obtain accurate repeatable positioning along one axis. The long tubing arms are flexible in the lateral direction. To restrict this dimension so that the male and female halves have coincidental axes, the tube is laterally guided part way up the tube.

To actuate the quick-connects, the head of a hydraulic cylinder is connected to each tube. Two hydraulic cylinders, one for each tube, are located inside of the stick as shown in Figure B-12. A block used for the purpose of attaching the piston rod to the tubes is also used to provide the necessary lateral guiding. A "U"-shaped guide confines the block.

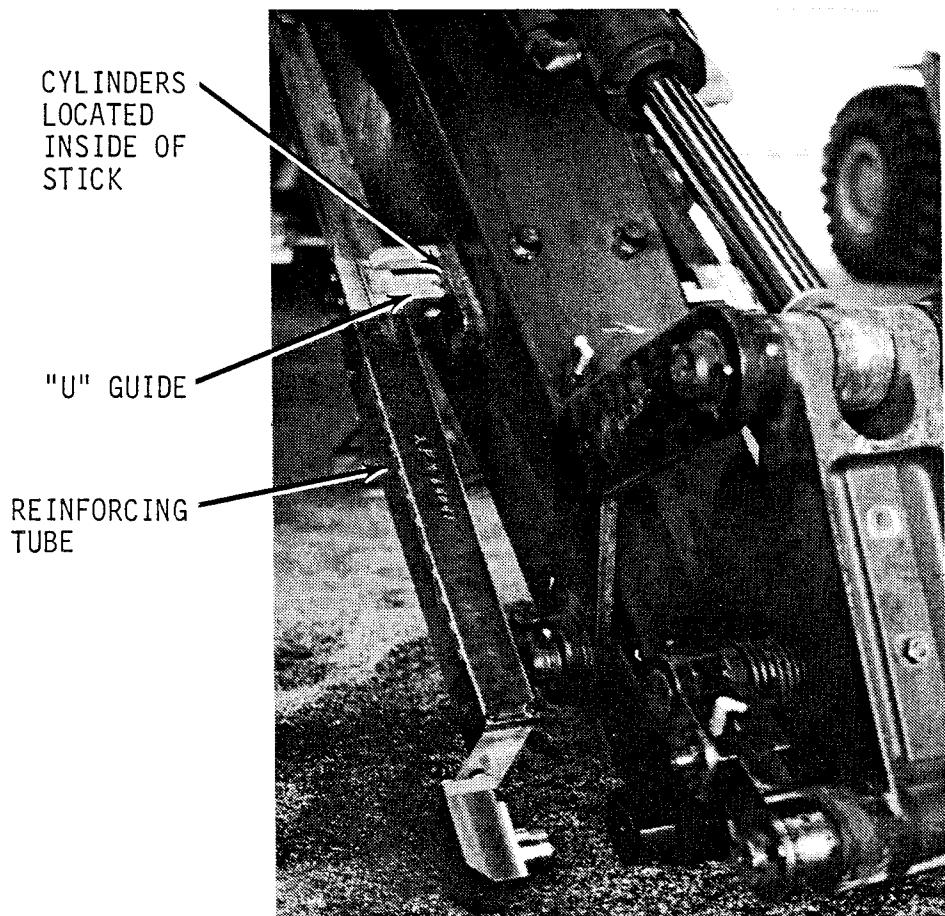


Figure B-12. Hydraulic Tube Activation Cylinders.

A design consideration was to have the guide, which insures accurate positioning of the two quick-connect halves, located as close as possible to the quick-connects. It was thought that a tapered pin with adequate lead into a hole would provide accurate alignment. However, the rotation of the arm of the toggle requires a clear space approximately 30 inches above the quick-connect. It was necessary, therefore, to relocate the lateral guide beyond this area on the stick. To ensure that the tubing would not deflect more than could be tolerated, the tubing was reinforced with a rectangular steel tube from the male quick-connect to the guide block. This is also shown in Figure B-12.

When the double-acting cylinders are activated in the connect mode, they pull in the arms and the male quick-connect engages with the female half (see Figure B-13). To disengage, the cylinders are extended. With the cylinder activated in the

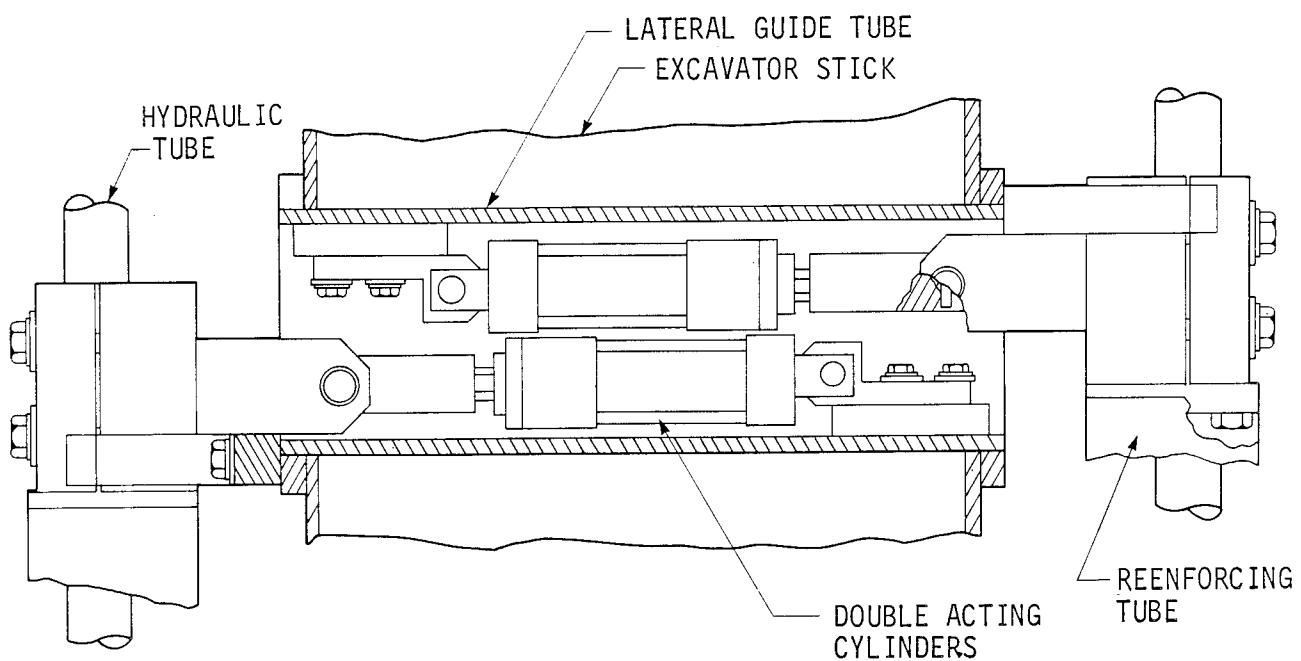


Figure B-13. Hydraulic Connect/Disconnect Activation Cylinders.

disconnect mode the arms move out from the stick, thus, separating the male and female halves, and the sealing sleeves return by spring action to reseal both halves.

The polyurethane seals, made by Microdot Corporation, are of the crown-seal type (see Figures B-14 and B-15). The urethane is a tough material designed for longwearing properties. A rubber O-ring under the seal provides resiliency to urge the seal against the steel sealing surface. The O-ring does not provide any sealing properties. Next to each seal is a bearing, manufactured by Shamban Corporation and made of glass-filled TFE. The bearings keep the seals concentric with the steel sealing surface and minimize wear of the seals. On the face of the female portion the TFE bearing was replaced with a bronze bearing, due to distortion of the crown-seal and the face bearing which retained it by internal hydraulic pressure.

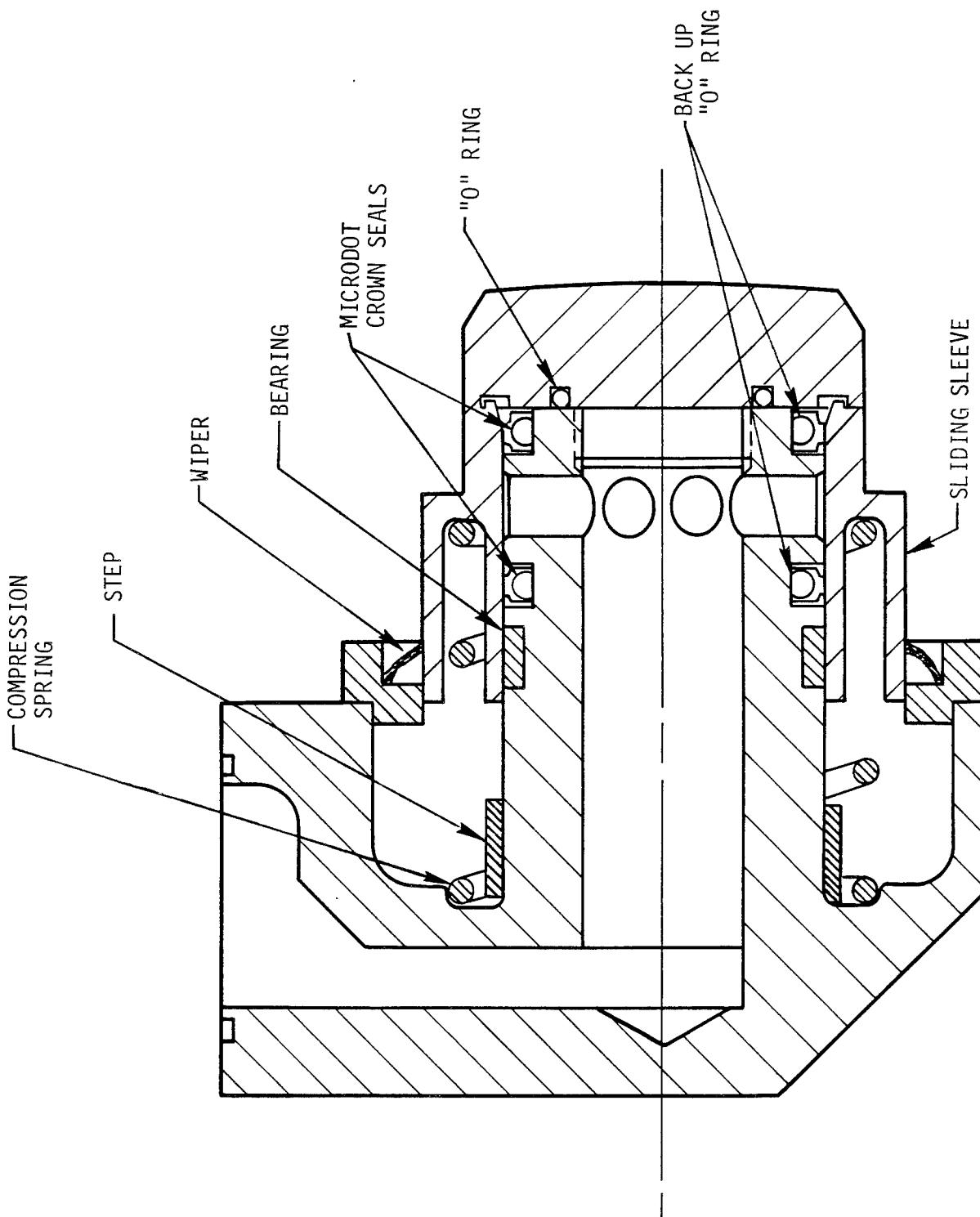


Figure B-14. Seal Components in Male Quick-Connect.

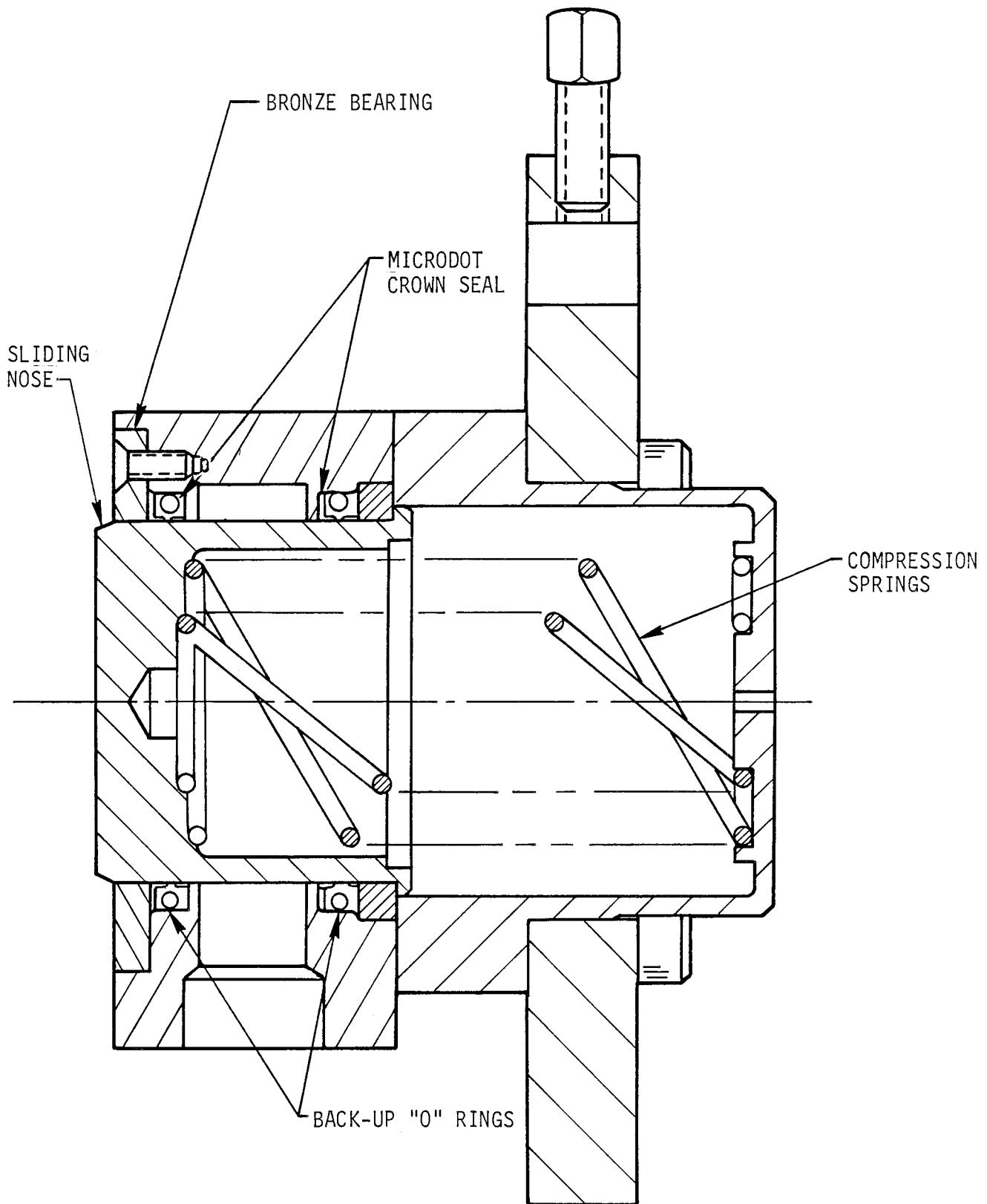


Figure B-15. Seal Components in Female Quick-Connect.

In an application where high pressures are involved, the surface finishes and clearance fits are critical. The finishes and fits recommended by the manufacturer were followed very closely. Upon assembly of the prototype units, several conditions became apparent that necessitated changes:

- The fits of the seals and bearings which were made according to the seal manufacturer specifications were too tight, making assembly difficult and requiring excessive force to mate the quick-connects axially.
- The high forces did not permit the sealing sleeve and the sliding nose to return when the halves were disconnected.
- Some chamfers were inadequate for sliding connections.
- A change in the female bearing and seal retainer was necessary to permit engagement of one seal.

The steel members were modified at appropriate locations to open the fits by 0.005 to 0.006 inch on the diameter. Certain chamfers and leads were improved. After several trial assemblies the components were fitted properly and provided adequate sealing. The return springs for the sliding sealing members were still found to be lacking adequate force. The compression springs were designed to provide a maximum force of approximately 100 pounds, and it was necessary to double this. New springs were used.

#### C. THE TOOL CARRIER

Several versions of a carrier device for the attachment tools were proposed. Foster-Miller originally proposed a tool carrier that, with relative compactness, satisfied the basic

needs. This design is shown in Figure B-16. In this approach the bucket is left attached to the excavator stick end and a structural member holds the other two tools: compactor and hammer. The carrier is supported via a lifting hook to the bucket. When this version was not accepted by the Government, two other versions that would carry all three tools were considered: one, a straight-line model was considered too long and cumbersome. The other, a curved arrangement, did not help resolve the deficiencies.

The prototype which was built and demonstrated is shown in Figure B-17. The specifications used to determine the design of the carrier resolved three basic considerations:

- Must be capable of holding the two hydraulic tools and the bucket even when tilted.
- Must be capable of being lifted and transported by the excavator and within its rated capacity.
- Must avoid application of excessive torque to the stick or boom.

In addition, the ease of placement and attachment of tools were kept in mind. The design was initiated by first arranging the three tools in a triangular fashion so that their centers of gravity would be located to apply approximately an equal moment upon the center of the attachment point of the carrier. To avoid high torques from being applied to the excavator stick the lateral center of gravity (C.G.) positions were located with heaviest tool as near central as possible and lighter ones moved outboard. In the fore and aft positions, the C.G. proved less critical if the carrier, containing all the tools, was lifted on its attachment ears. The swing of the carrier was then such that the ears would remain engaged. The structure of the carrier was also analyzed for its C.G. contribution as well

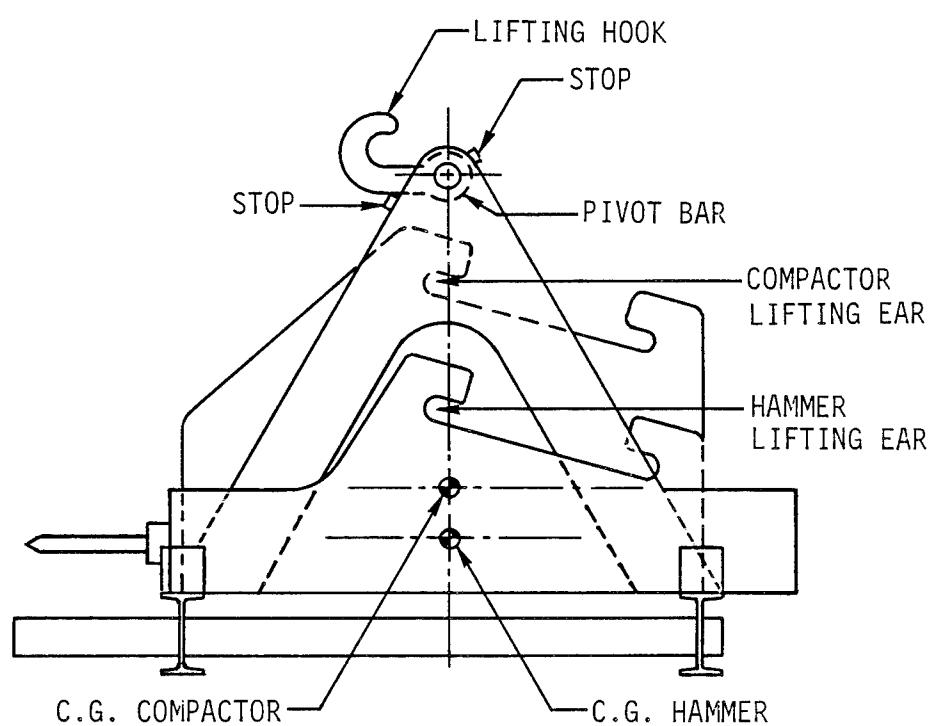
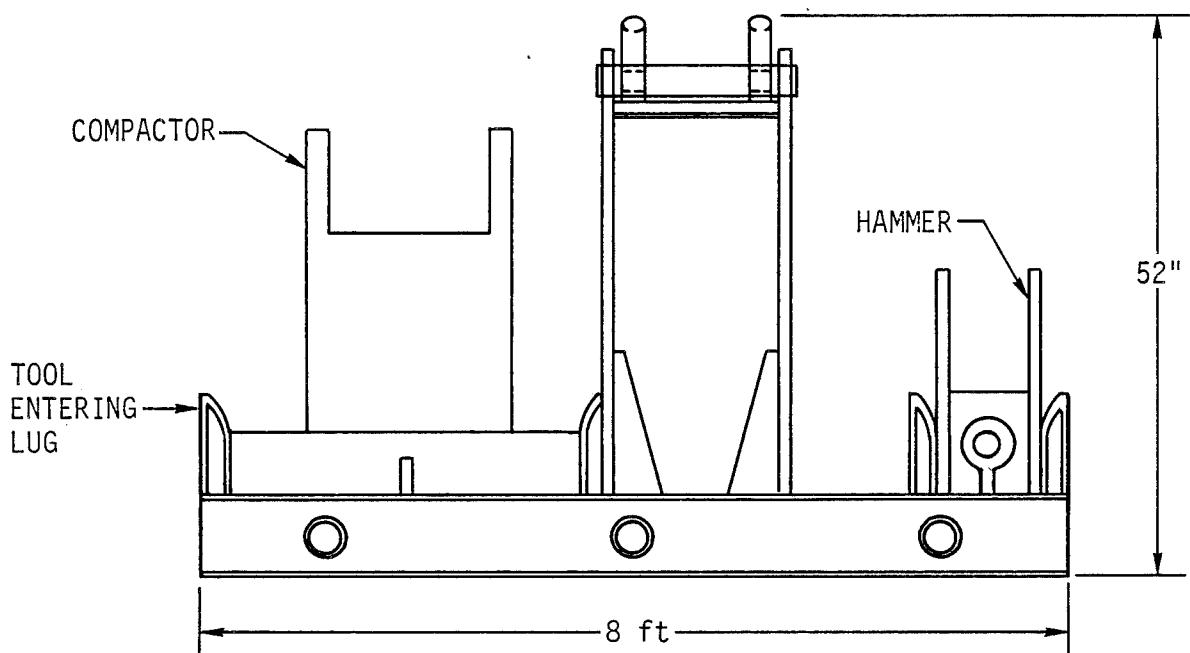


Figure B-16. Original Proposed Tool Carrier Concept.

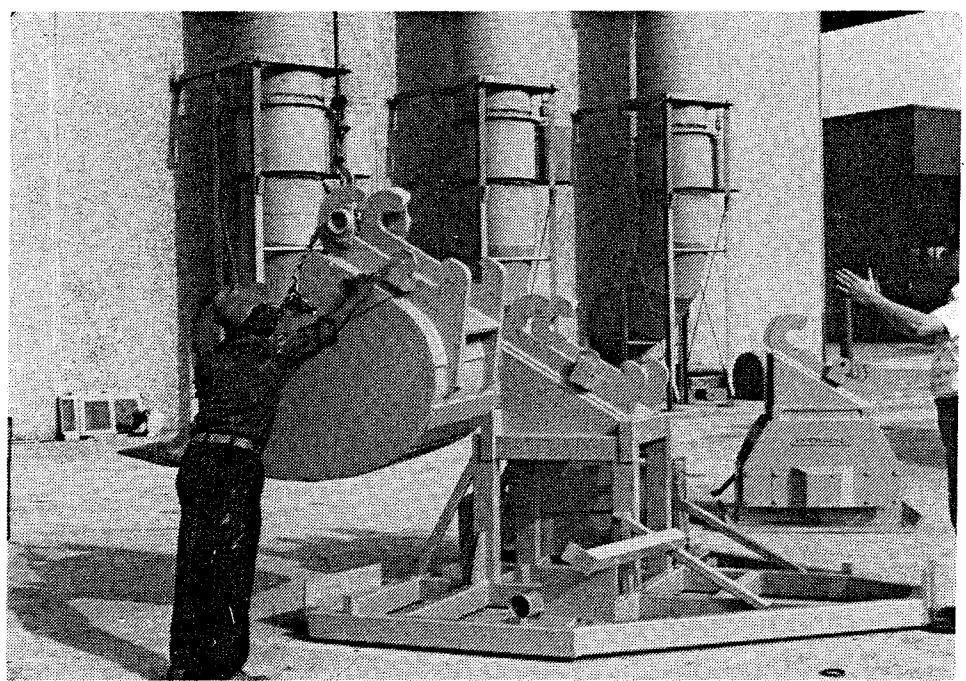
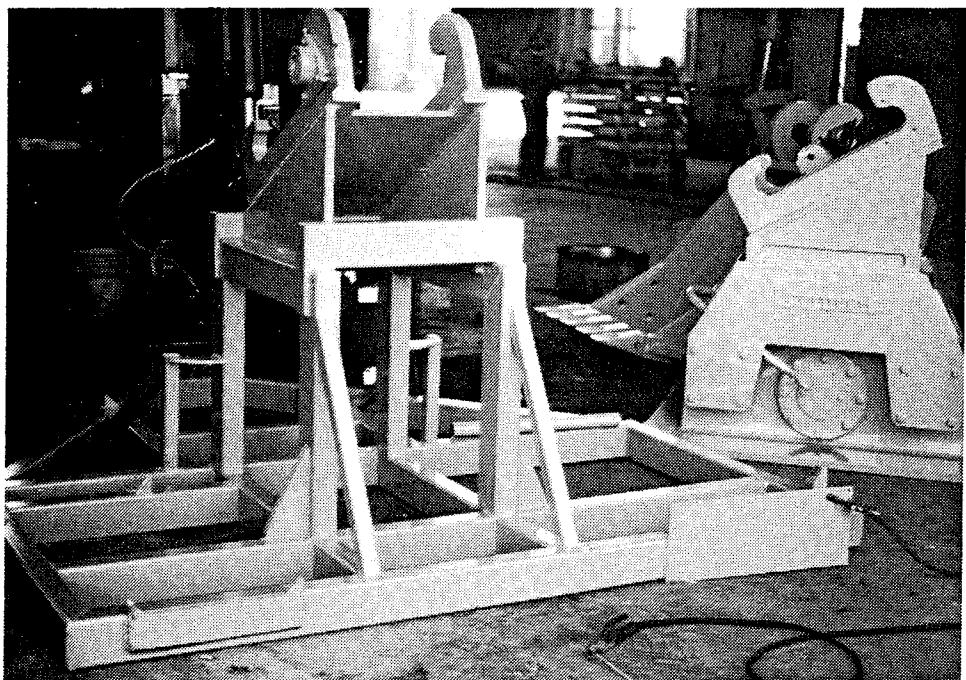


Figure B-17. Back and Side Views of the Tool Carrier.

as its structural integrity. Note in Figure B-17 that the attachment ears on the carrier are identical to those on each tool. The angle at which the ears repose is important to facilitate pickup and engagement by the excavator operator. It was also necessary to provide adequate clearance between each of the ears and arrange the tools so that their elevations do not inhibit manipulations. This can be seen in the loaded tool carrier shown in Figure B-18.

During the initial assembly, the tool locating pads were only tack-welded and the tools were positioned on the carrier. With the tools very near to their intended location, the carrier was supported at the center of its pickup point, and it balanced quite well. Locating pads were adjusted and some were improved to hold each tool more positively. Figures B-19 and B-20 show the locating pads for the bucket and the compactor plate, respectively, while Figure B-21 shows the locating pads for the hydraulic hammer.

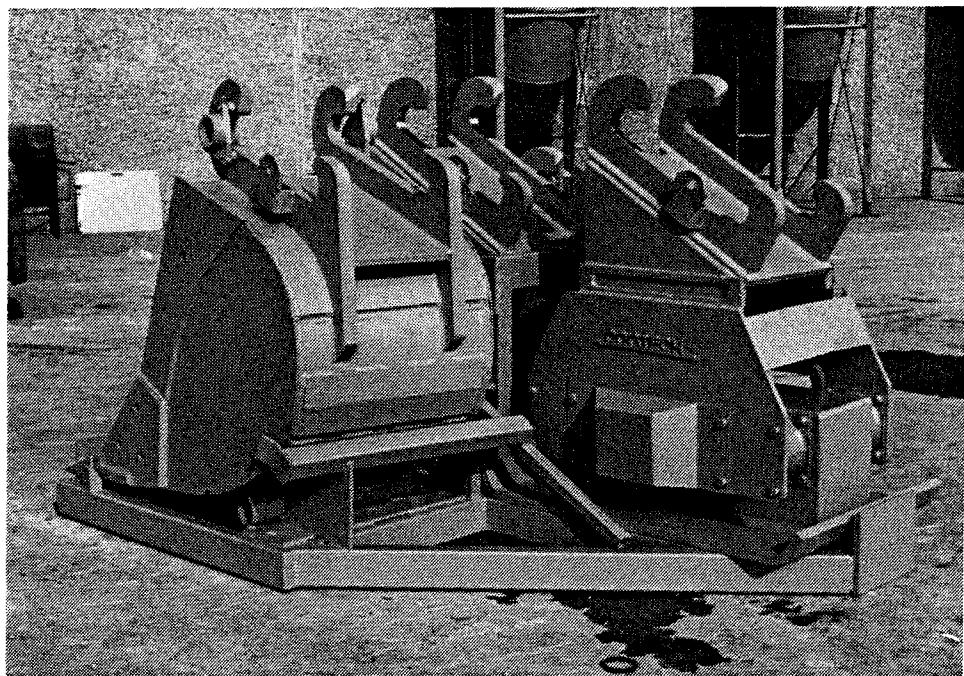


Figure B-18. Loaded Tool Carrier.

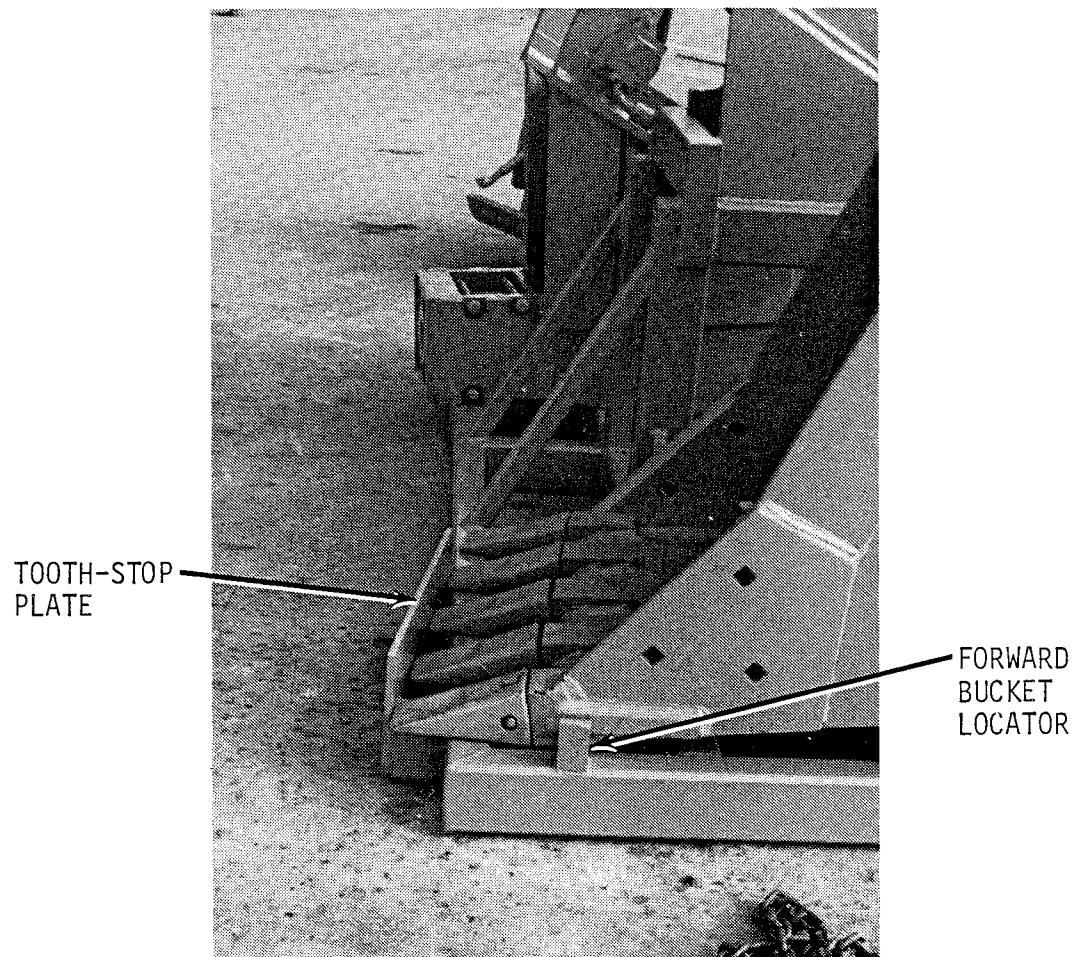
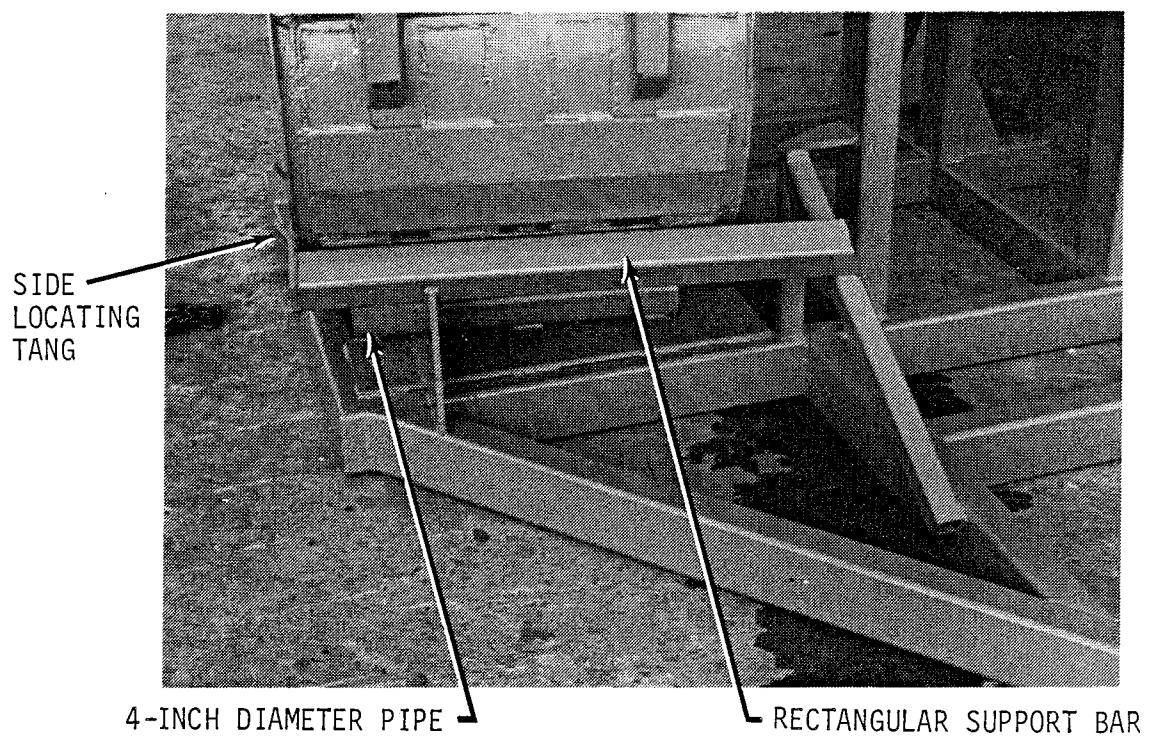


Figure B-19. Support System for Bucket Location.

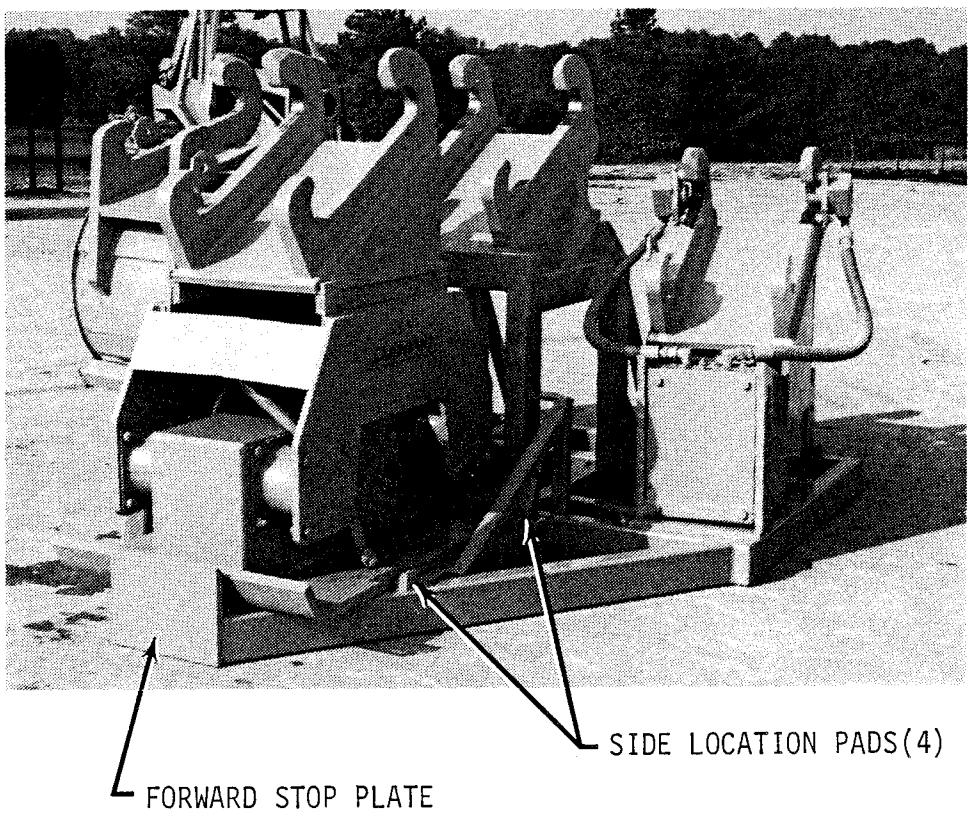
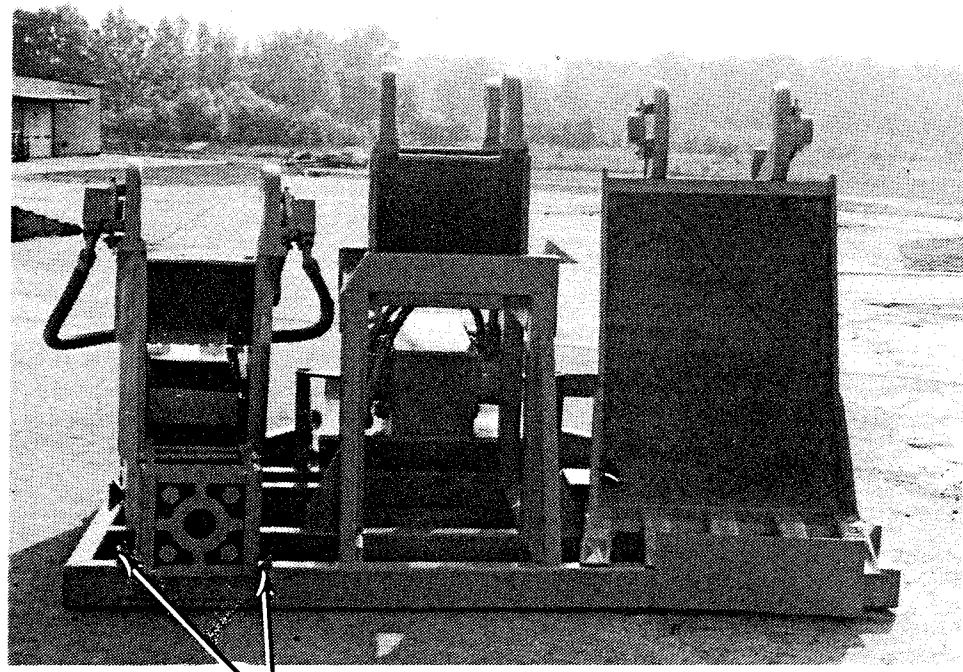


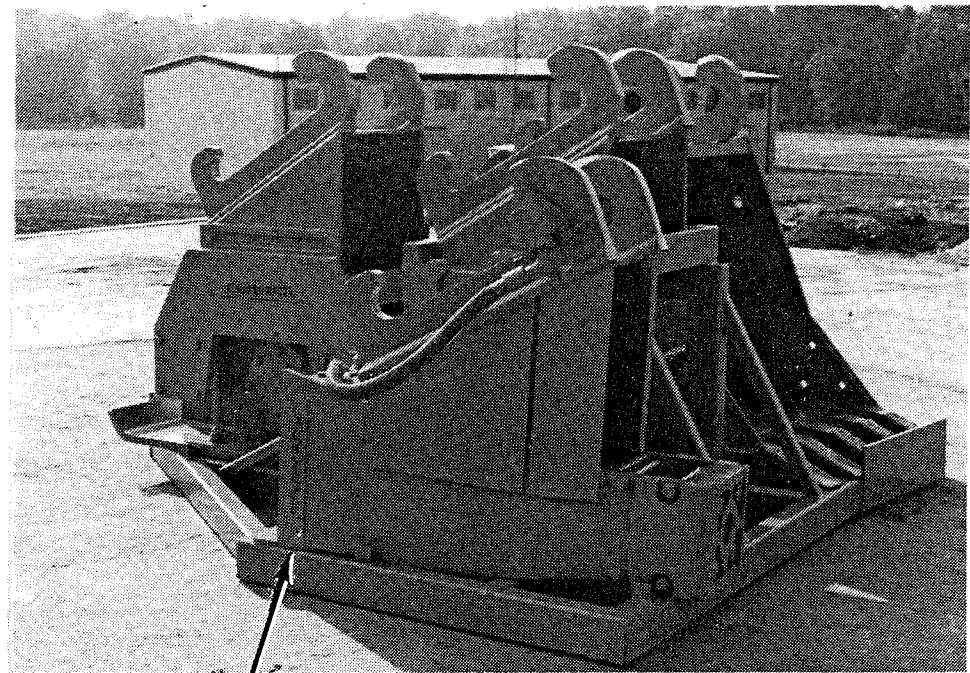
Figure B-20. Support System for Compactor Plate.

When the excavator is aligned with the ears of the tool carrier, the ears of the compactor are approximately on the same centerline and parallel to the carrier ears. The compactor is positioned just forward of the carrier ears. To facilitate pickup of the bucket and the hammer, which are on either side of the carrier ears, they are canted at a slight angle. This is so the operator need not reposition the excavator laterally, but merely rotate it to pick up either tool. The angle at which these two tools are set approximates the angle through which the excavator must swing about its vertical axis.

To pick up the tool carrier the excavator must be free of any tool. The tools should be placed on the carrier and then the entire set lifted (see Figure B-22). The carrier should not be lifted with one of the tools removed; this will cause a loss of balance. The carrier may also be lifted when it is empty of all tools.

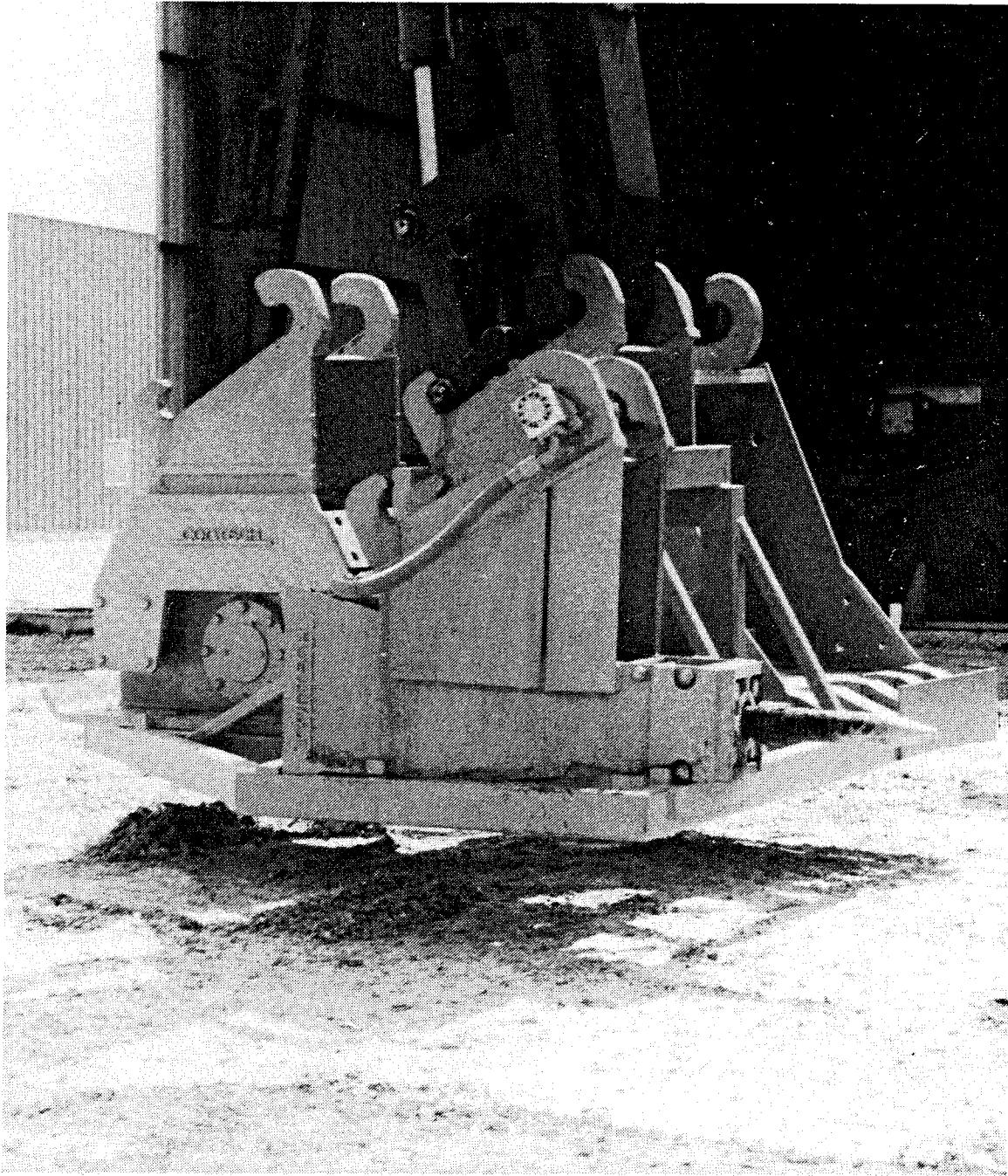


SIDE LOCATION TABS (4)



RECESS IN RECTANGULAR TUBING ACCEPTS  
TANG ON SIDE PLATE OF HAMMER

Figure B-21. Support System for the Hydraulic Hammer.



**Figure B-22. Loaded Tool Carrier Supported by John Deere Excavator.**

#### D. FABRICATION AND ASSEMBLY TASKS

In November, 1985, the work consisted of the following tasks:

- Prepare design layouts for the hydraulic quick-connect.
- Prepare design layouts for the four-bar tool attachment linkage.
- Review layouts at a meeting held at Caterpillar Tractor in Peoria.
- Revise the layouts as required.
- Perform the PDR at Tyndall AFB.
- Begin preparing fabrication drawings.

As described earlier in this report, design layouts of the four-bar linkage were started. The layouts included a design of the two toggle links, a powered pin for the reaction and locking functions, incorporation of a rotary joint for transmission of hydraulic power and an area was reserved for the hydraulic male/female quick-connects.

Simultaneously, layouts were prepared for the quick-connects. These layouts defined overall size, number and types of seals and methods of keeping the sealing faces free of contaminants.

Once these two areas were complete the design of the hydraulic quick-connects was integrated into the overall four-bar linkage. Additional mechanisms were designed for guiding the connector halves together. A preliminary layout of the tool carrier was also produced.

A design review meeting was held at Caterpillar's facilities on November 12th and 13th, 1985. During this meeting a major design flaw was discovered. If the reaction/locking pin is in the wrong position during operation it is possible to damage the four-bar linkage - a development that was confirmed during the testing of the Case four-bar connection design. The attendees also agreed that a more substantial rotary joint was needed and if it could be located on the centerline of the stick pin we would be able to minimize the number and lengths of the hoses required.

After fabrication was complete, assembly of the hydraulic quick-connect swivel and the excavator toggle connection was initiated. The 30-inch bucket and hammer had connecting ears welded to them.

Assembly instructions for the hydraulic parts were prepared and Foster-Miller personnel visited Caterpillar to facilitate assembly and test. The mechanized toggle connection to each tool was accomplished satisfactorily after some modification.

The hydraulic quick-connect/swivel was assembled and tested at the Caterpillar Peoria facility. The individual units and the assembly required extensive modification to enable them to function properly and withstand 2,500 psi.

The toggle arrangement which provides quick connection of each of the tools to the excavator, was also modified, assembled and demonstrated at the Caterpillar facility. The debugging and assembly consisted of the following steps:

- Modifications were made to the excavator stick. This included fabricating lands for the pivot adaptor and welding them to the stick. It also included cutting the stick for the addition of the lateral box beam

which houses the quick-connect cylinders for the male/female hydraulic coupler. See Figure B-23.

- Addition of an independent hydraulic power supply to provide hydraulic power for the quick-connect cylinders and the TAC lock pin. The 800 psi system was located on board the excavator and the pump was operated from the excavator battery. Figure B-24 shows the hydraulic power supply and its location on the excavator. Figure B-25 shows the controls that were added in the cab.
- Hoses were assembled and routed from the independent hydraulic power supply to the TAC lock pin and the hydraulic cylinders. The hoses run over the top of the boom and down through the inside of the stick so as to minimize vulnerability. See Figures B-26, B-27 and B-28.
- The hydraulic tubes were mounted to the pivot blocks near the top of the stick and the actuation cylinders were attached to the inside of the lateral box. All hydraulic connections were made. Stiffeners were fabricated and welded to the hydraulic tubes. See Figure B-29.
- The original linkage at the end of the stick was removed and replaced with the TAC linkage and a rubber bumper which was added to force the toggle linkage to go over center during the tool attachment procedure. See Figure B-30.

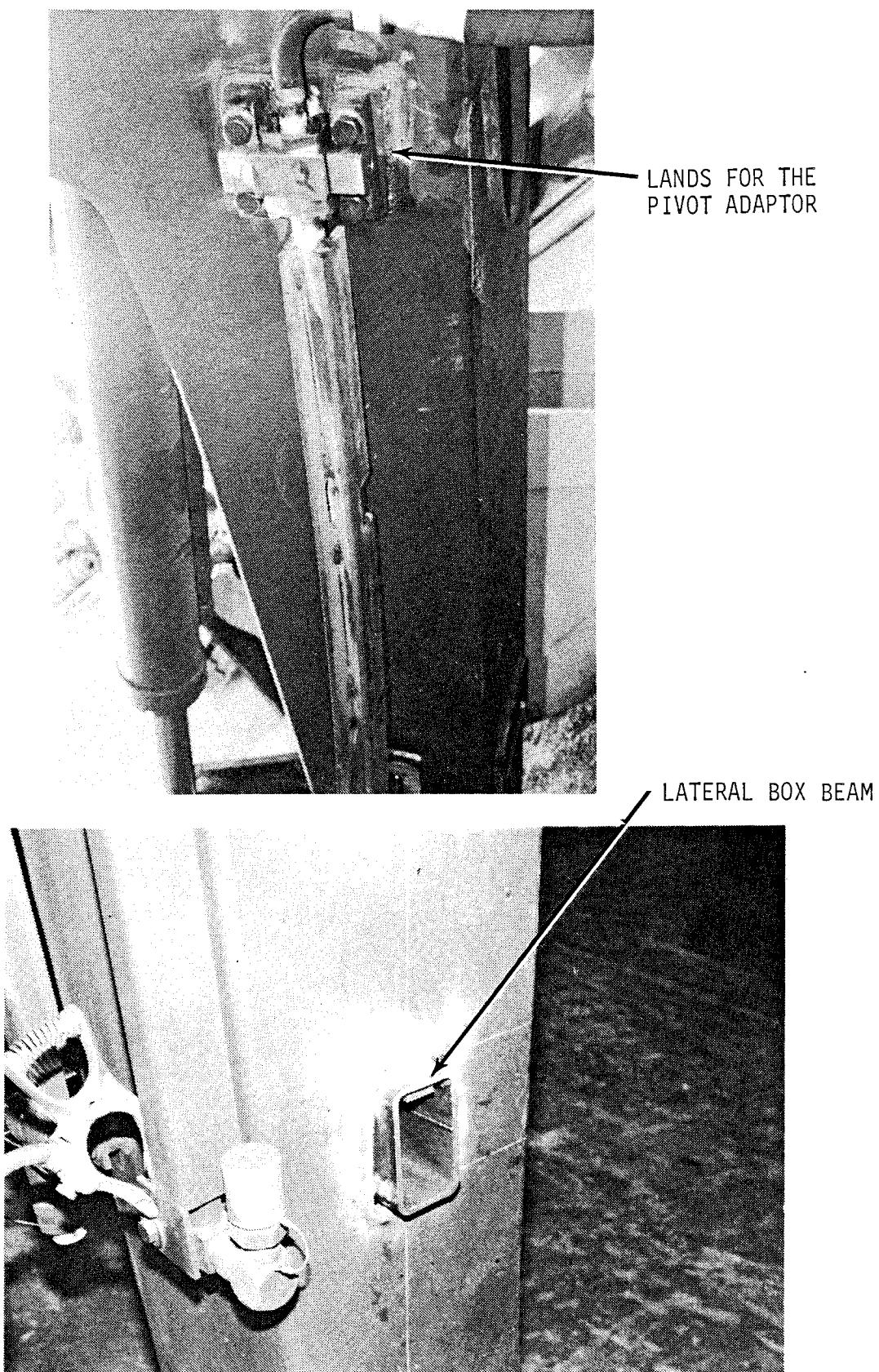
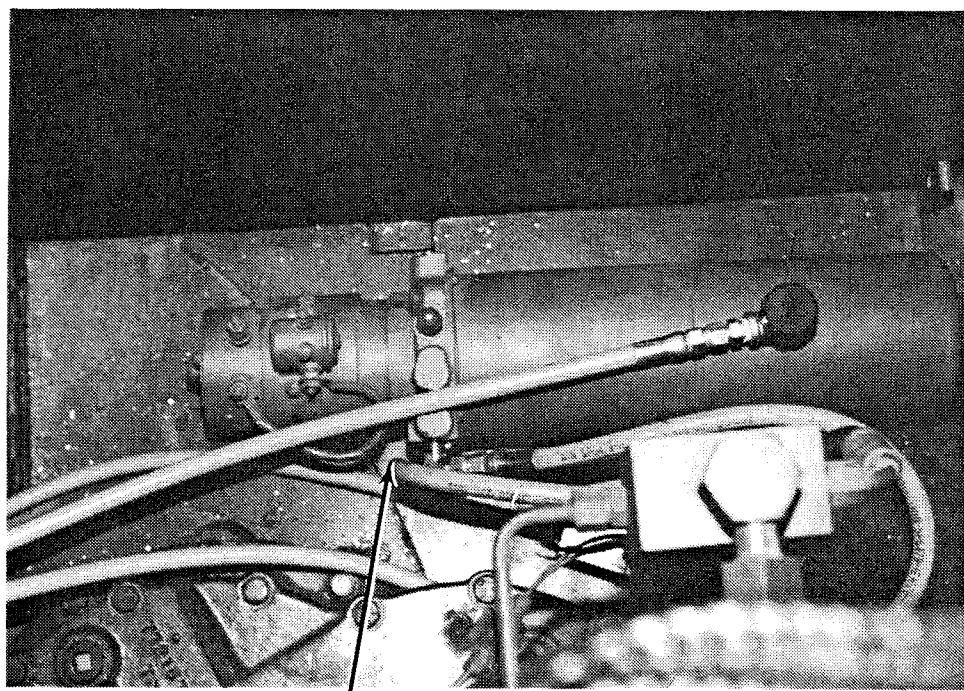


Figure B-23. Modifications to the Excavator Stick.



INDEPENDENT HYDRAULIC POWER SUPPLY

POWER SUPPLY LOCATION

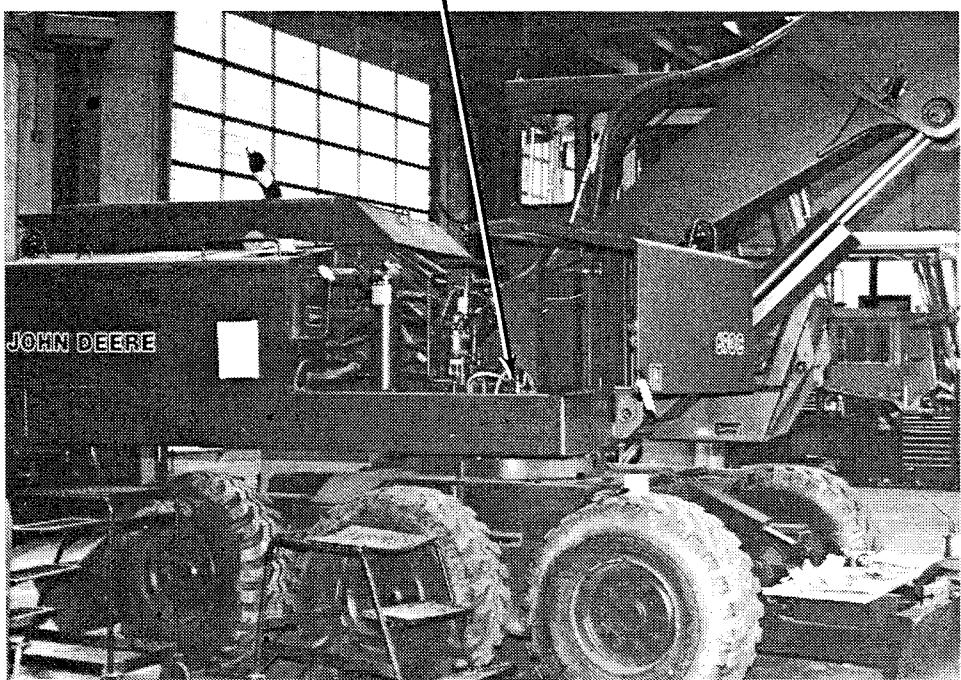


Figure B-24. Independent Hydraulic Power Supply and Its Location.



Figure B-25. Controls for Independent Hydraulic Power Supply.

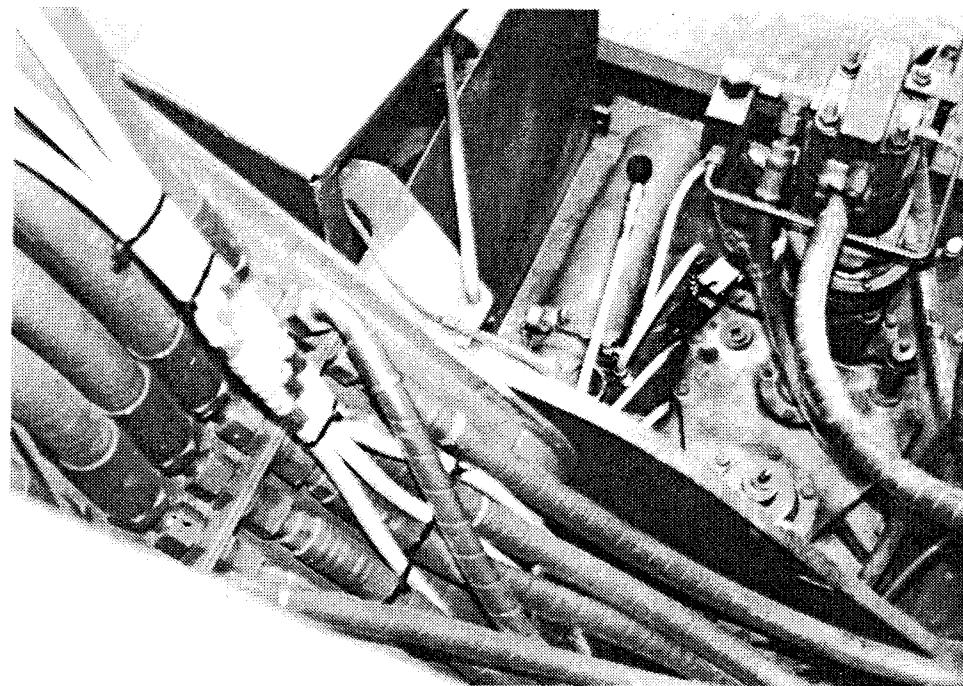


Figure B-26. Hoses Running from the Hydraulic Power Supply.

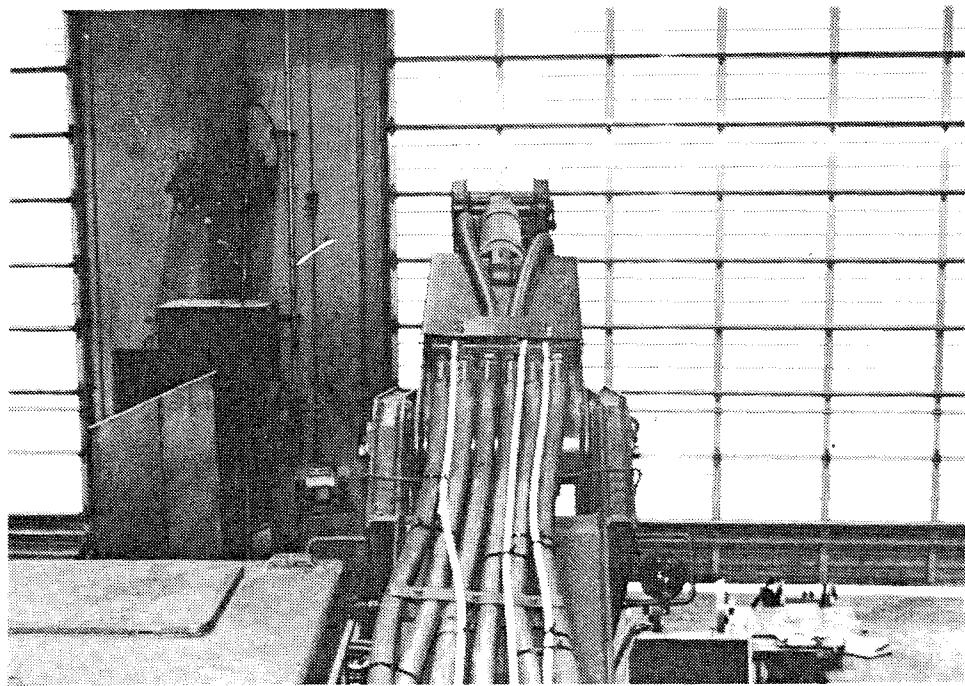


Figure B-27. Hoses Running Over the Top of the Boom.

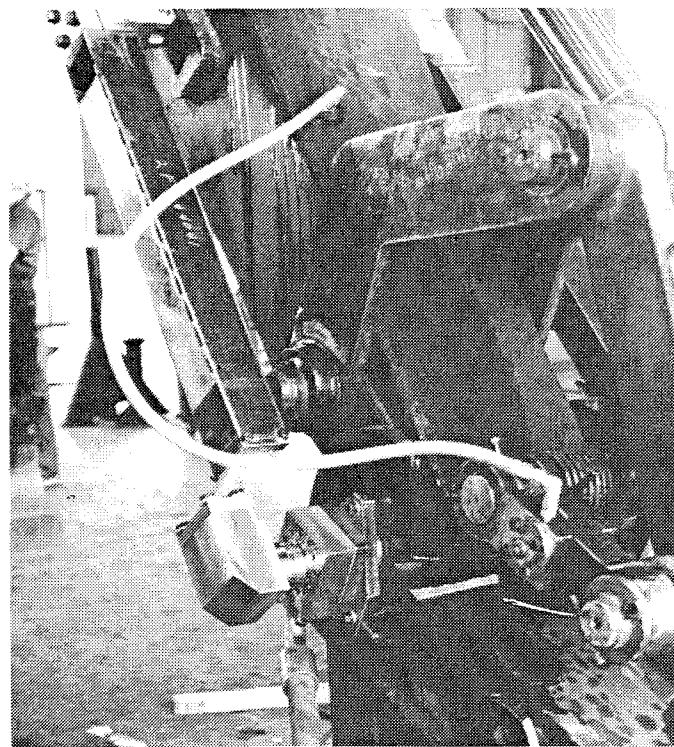


Figure B-28. Hose Emerging from Stick and Running to TAC Lock Pin.

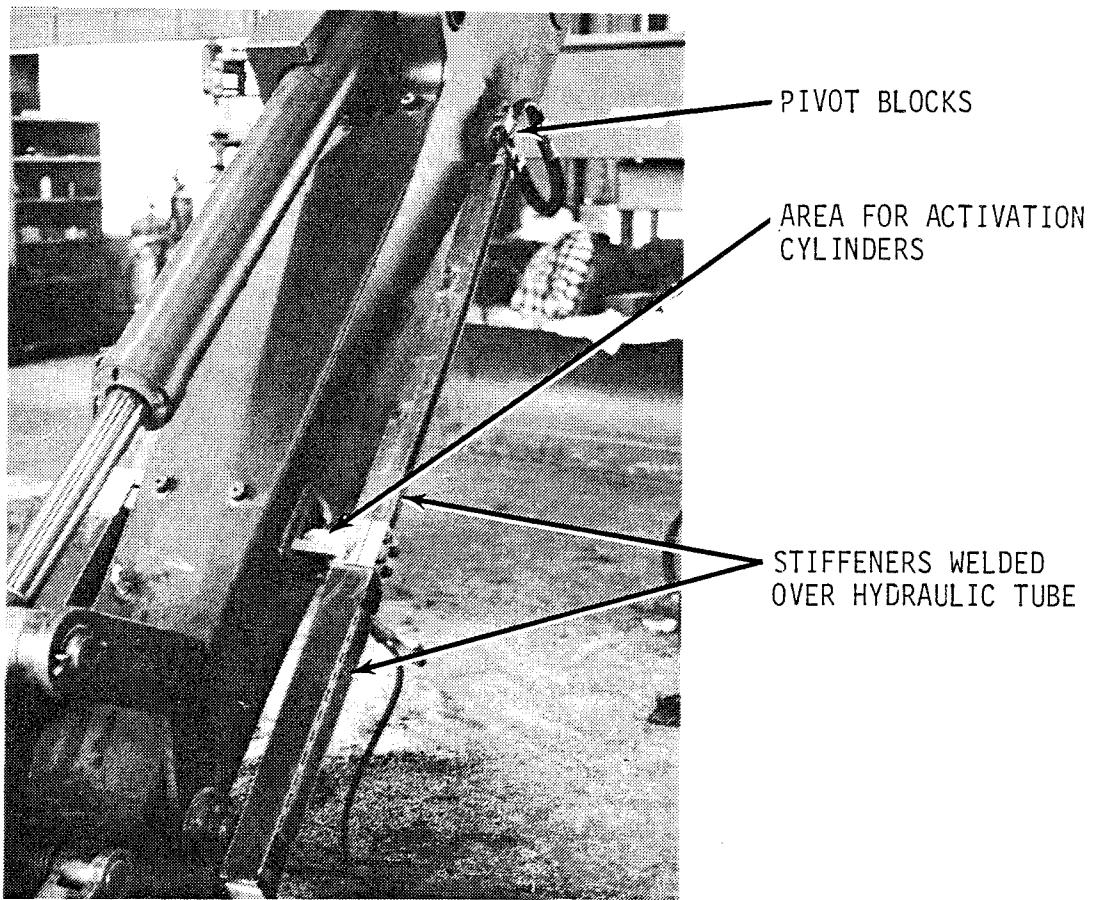


Figure B-29. Hydraulic Tubes and Stiffeners.

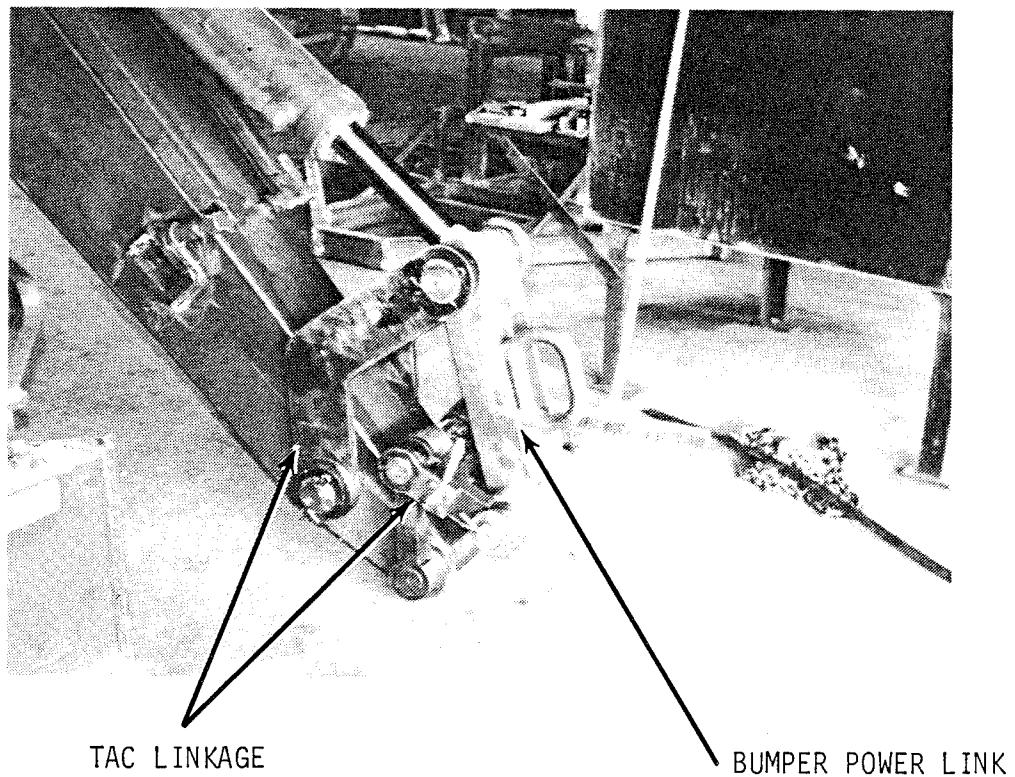


Figure B-30. TAC Linkage Attached to Stick.

- The ear assembly (horizontal plate and the two vertical ears) was welded to the compactor. See Figure B-31.
- The male and female coupler halves were mounted to the bottom ends of the hydraulic tubes and to the tool ears, respectively. The female coupler is resiliently mounted to the ears through the use of three rubber mounts which helps to facilitate correct alignment as the hydraulic quick-connects come together. Figure B-32 shows the mated pair.
- The last step needed to complete the hydraulic circuit was to add armored hose from the female connector on the ear of the tool to the tool ports. Figure B-33 shows this feature on the hydraulic hammer.

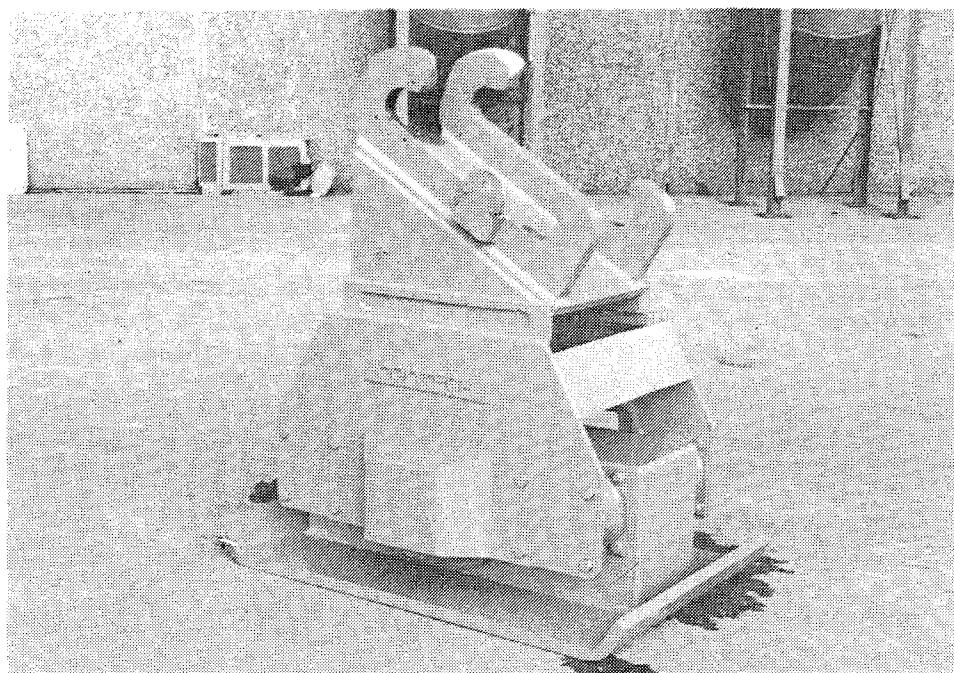


Figure B-31. Ear Assembly Welded to Compactor.

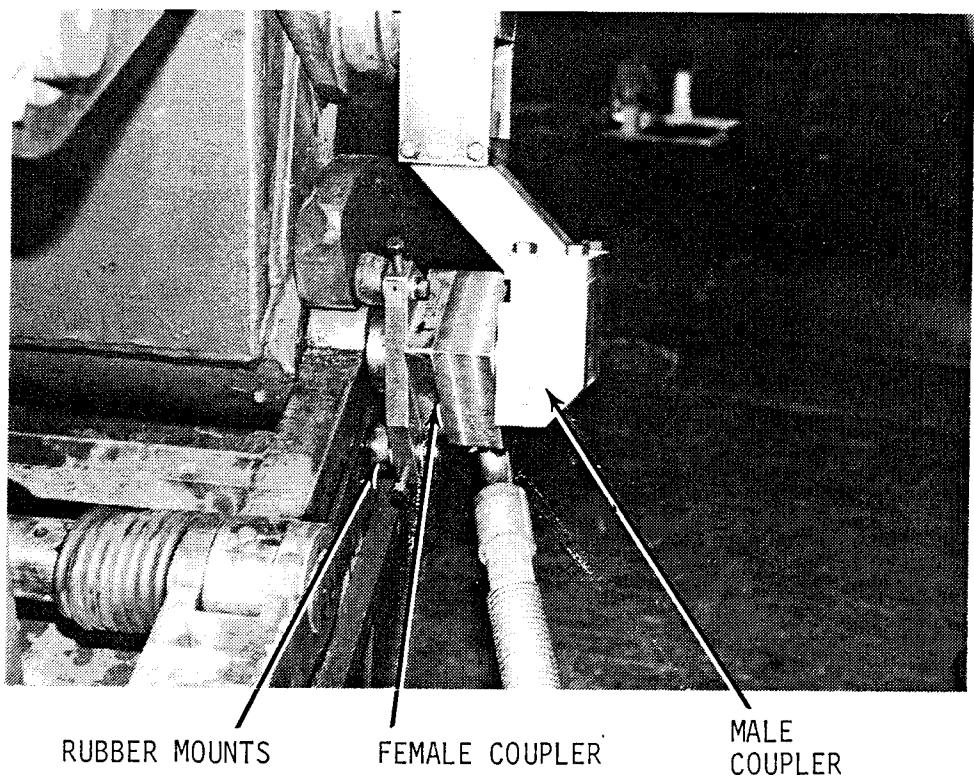


Figure B-32. Mated Hydraulic Quick-Connects.

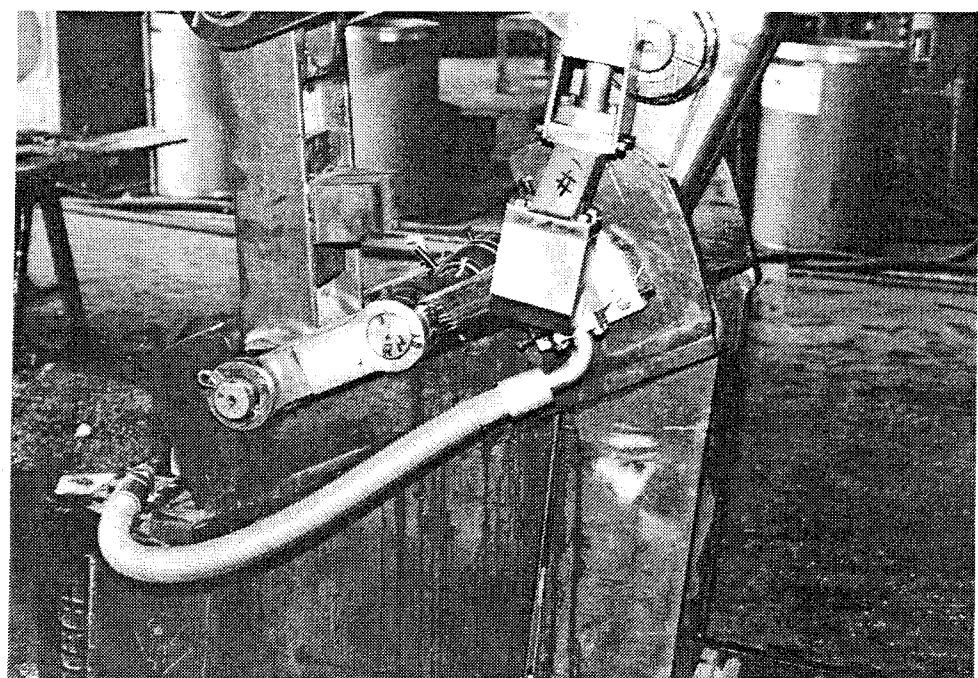


Figure B-33. Armored Hose On Hydraulic Hammer.

The completed system required a significant amount of debugging. Most of the problems were related to the hydraulic system but the two biggest problems were related to the hydraulic quick-connect and the fit between the TAC mechanism and the ears on the tools and tool carrier.

The tight fits required on all of the sealing surfaces for both of the hydraulic coupler halves required us to use very high forces to push them together; but conversely, once they were coupled, they tended to stick. The assemblies were reworked several times before they worked successfully.

The relationship between the TAC mechanism and the center-to-center distances of the ears was critical. We used the same tolerancing scheme that CAT had used with their prototype, but this was inadequate. Much hand grinding eventually solved the problem.

After the debugging was completed the system was cleaned, painted, and shipped to Tyndall AFB.

#### E. TESTING AT TYNDALL AIR FORCE BASE

Testing at Tyndall AFB was conducted during the week of May 5 , 1986 and was guided by the Foster-Miller test plan.

##### 1. Objectives

The objective of the test was to demonstrate the performance of the hydraulic quick-connect system and the tool carrying device.

To this end the test plan was designed to demonstrate:

- The three tools (bucket, hammer, and compactor) mating to the 690C without degradation in performance.

- Each tool-to-tool change accomplished by a practiced operator within 1 minute.
- Environment integrity of the hydraulic component of the quick-disconnect.

Demonstrations of equivalent performance (modified John Deere 690C excavator as compared to currently existing machines) was to be accomplished by demonstration of the following two parameters:

- Force transmission capability: The new connection must be able to transmit the same forces from the tool in operation to the boom as the present design (the Government is responsible for supplying load cells, recording equipment, etc.).
- Control capability: The new connection must have equivalent or less play than the present design.

It was also our intention to demonstrate the environmental integrity of the design by means of operation for a suitable period under the RRR rain testing facility, which was to be supplied by the Government.

## 2. Test Procedure

The test was designed to demonstrate tool swapping at the required rate and the adequacy of the carrying device by a specific test sequence which eliminates - to the degree possible - other factors which might affect the operator.

This was accomplished by following the following sequence:

- Place the carrying device on the ground. (Timing started when the device hit the ground.)
- Pick up the bucket with the linkage, lift it slightly and put it back on the carrying device. Disconnect and move to the hammer position.
- Pick up the hammer with the linkage, lift it slightly and put it back on the carrying device. Disconnect and move to the compactor position.
- Pick up the compactor with the linkage, lift it slightly and put it back on the carrying device. Disconnect and reposition the boom over the carrying device.
- Pick up the carrying device. (End timing at the point when the carrying device just lifts off the ground.)
- Record time.
- Repeat the first six steps.
- Return carrying device to the ground.
- Average the times.

The recorded total time for the first eight steps shall not exceed 8 minutes.

### 3. Testing

Testing to support the first objective was carried out in accordance with the procedure outlined above. Figures B-34 through B-38 show each of the steps in the procedure.

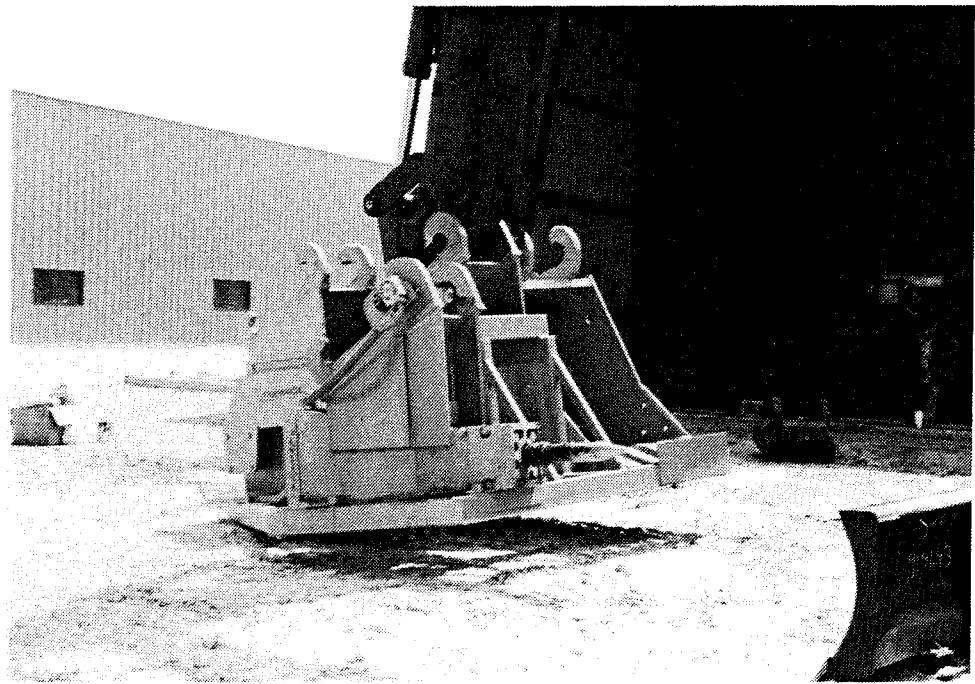


Figure B-34. Step No. 1 - Place Tool-Carrying Device on the Ground.

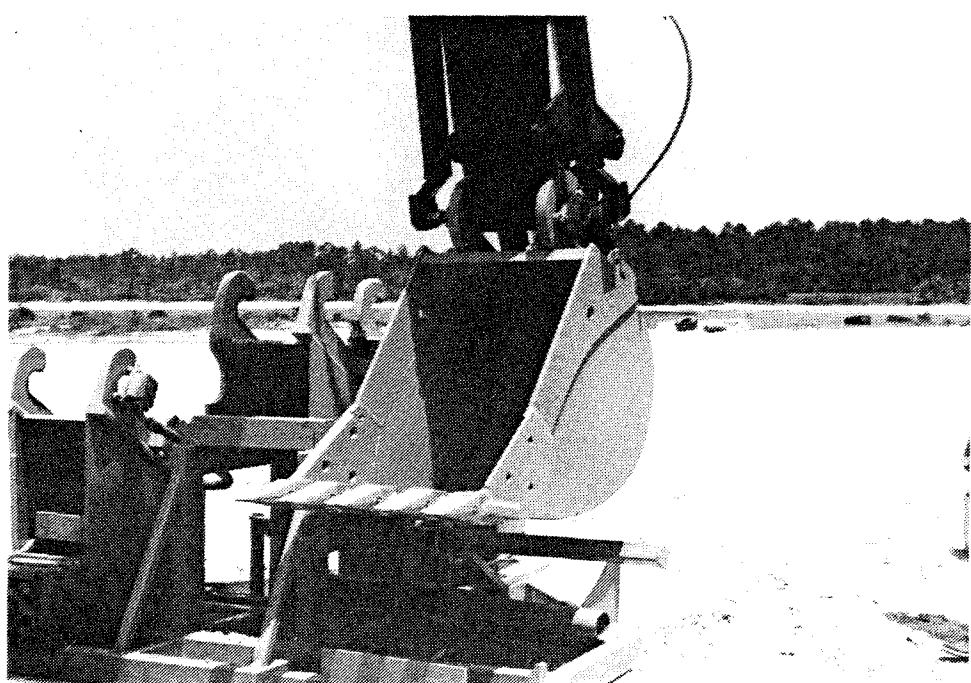


Figure B-35. Step No. 2 - Pick Up the Bucket.

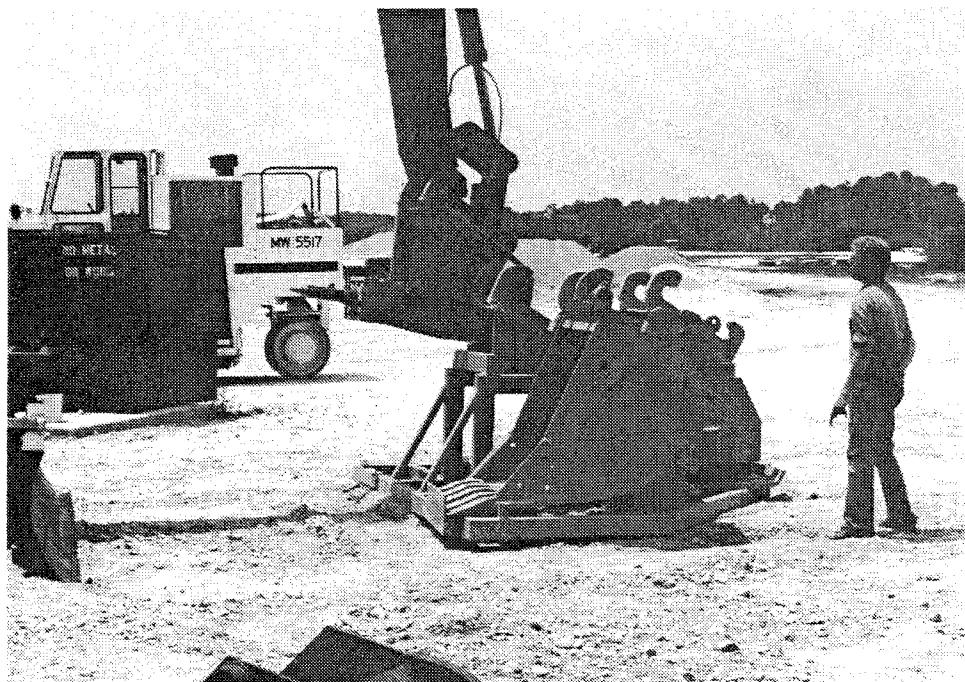


Figure B-36. Step No. 3 - Pick Up the Hydraulic Hammer.

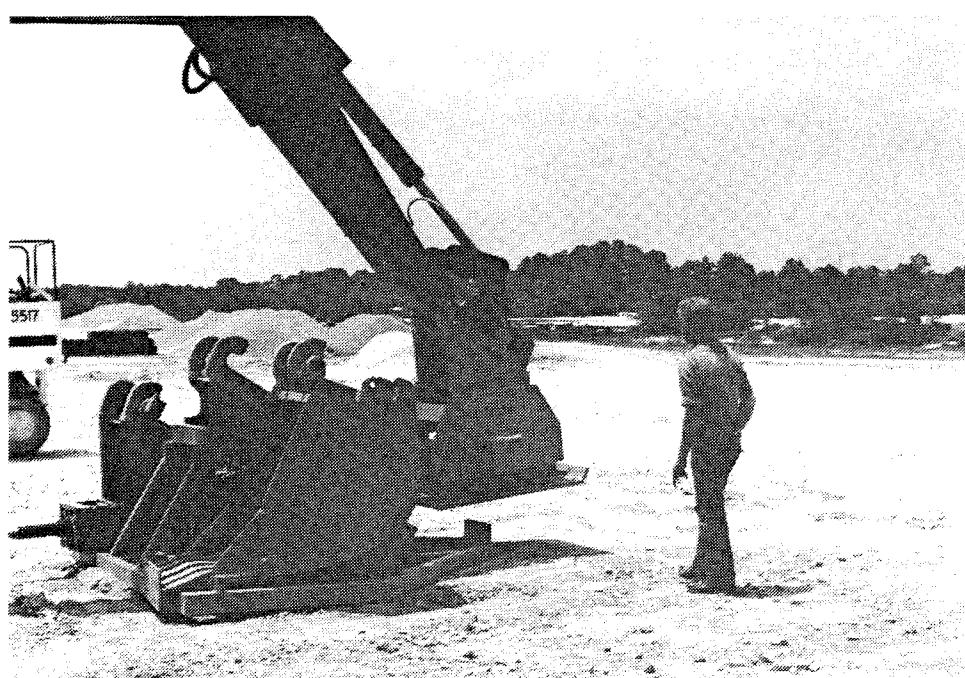


Figure B-37. Step No. 4 - Pick Up the Hydraulic Compactor.

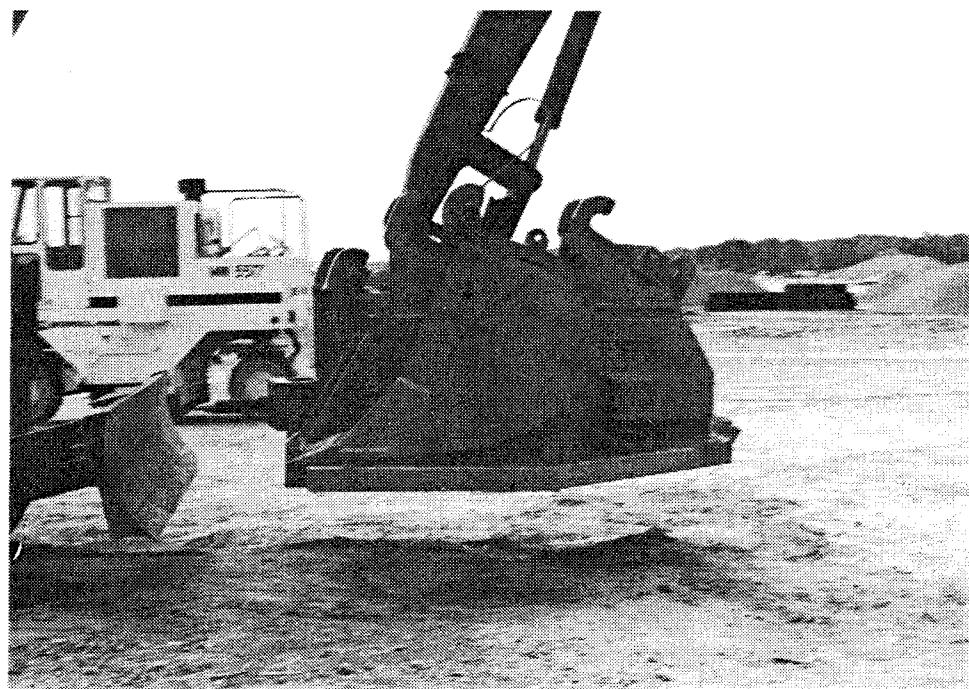


Figure B-38. Step No. 5 - Pick Up the Tool Carrying Device.

The eight-step procedure was performed twice in accordance with the plan. Times of 4 minutes, 20 seconds and 3 minutes, 55 seconds were recorded. The average time for each tool change was 30.9 seconds, far less than the required specification of 1 minute.

In addition to these tests, the operator dug several shallow trenches with the bucket and operated the hydraulic hammer. Finally, the excavator trammed the entire system over unpaved terrain as shown in Figure B-39.

Prior to the procedures just described, Foster-Miller and Caterpillar broke the excavator's power link during the final system check-out. The problem occurred when attempting to couple to the hydraulic compactor. Due to operator error the toggle linkage got jammed between the two pick-up ears. As the



Figure B-39. Excavator Tramming Over Unpaved Terrain with Loaded Tool Carrier

operator continued to extend the curl cylinder, the power link was put in compression. The configuration which caused the resulting fracture is shown in Figure B-40. In the future this problem can be avoided by providing a radius to the face of the forward ear. This configuration, which is shown in Figure B-41, will force the leading edge of the short toggle link to either fall into the recess or ride over the top surface.

The government elected not to conduct further testing. For this reason, environmental integrity, force transmission capability, and control capability were not evaluated.

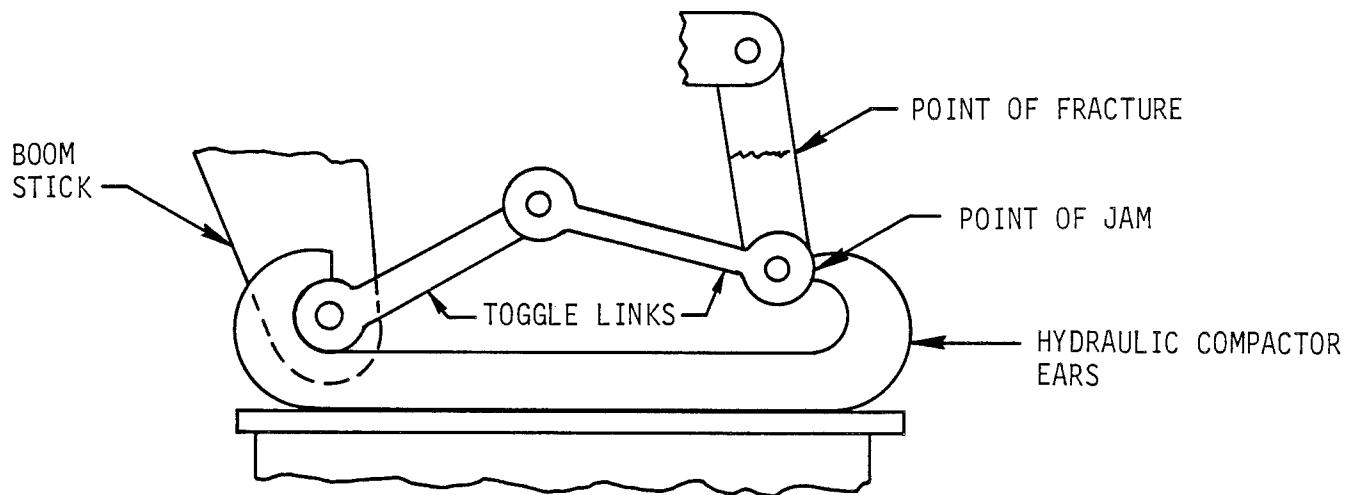


Figure B-40. Conditions Causing Fracture of the Power Link

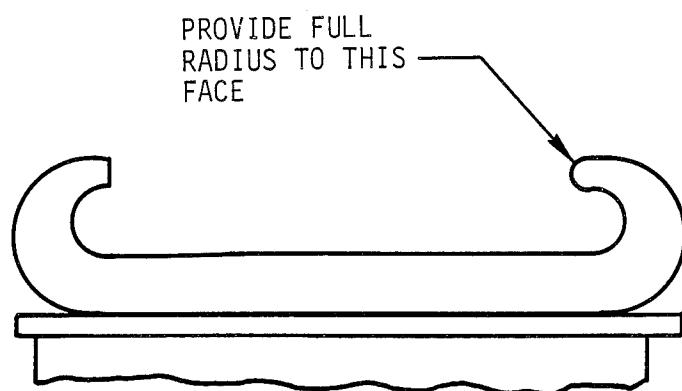


Figure B-41. Modification for Avoiding Toggle Link Jamming

## SECTION III

### CONCLUSIONS

The development program accomplished the following:

- Demonstrated a mechanized quick-connect system which will allow the operator of a John Deere 690C excavator to make tool-to-tool changes in less than 1 minute.
- Tool changes include making an automatic hydraulic connection as well as the mechanical connection.
- All operations can be accomplished by the operator from the cab of the excavator.

The testing activities indicated that the following design changes would be required to achieve reliable operation:

- Relocate the hydraulic hose that runs from the stick to the TAC lock pin such that there is no possibility of it becoming jammed in the TAC mechanism and so that its exposed run is shorter than in the current version.
- Redesign the tool carrier attachment so that it does not have to be lifted off the ground to attach it to the excavator stick.
- Redesign to the extent necessary to move the C.G. of the tool carrying device towards the excavator.

- Move the TAC lock pin to the opposite side of the mechanism so the operator can visually verify when the pin is in the locked position.
- Rework the TAC lock pin to eliminate galling and jamming of the pin.

APPENDIX C

DESIGN "A" QUICK-CONNECT TEST

David Lyle Reed

BDM Corporation  
7915 Jones Branch Drive  
McLean, VA 22101

## SECTION I

### INTRODUCTION

#### A. PURPOSE

The purpose of this test was to evaluate a tool quick-connect and quick-disconnect system developed by Consolidated Technologies Corporation (CONTEC) for the RRR excavator. The system's design requirement was that tool-to-tool changes be done in 1 minute or less without degrading excavator performance. Tool change times and the effectiveness of the hydraulic connection dust covers, the bucket dirt shield, and the tool carrier were evaluated during this test to determine the degree to which CONTEC fulfilled its Statement of Work (SOW) requirements. In addition, the survivability of the hydraulic quick-connects, in extended operations with the hammer and compaction plate, was evaluated.

#### B. BACKGROUND

The Rapid Runway Repair (RRR) excavator can accomplish a wide range of bomb crater repair tasks by attaching a variety of tools to its boom. The excavator can remove debris and broken pavement from within and around a crater by using a bucket, can break upheaved pavement using a moil (hammer), or can compact crushed stone in a crater using a compaction plate. The RRR excavator, with tool carrier attached, is shown in Figure C-1.

At the present, each of these tools (bucket, hammer, and plate) must be attached manually to the excavator boom. This tool-changing process currently requires 3 to 8 minutes. Additionally, changing tools either requires two personnel, or the operator must exit the protective armored cab at least twice during each change.

#### C. OBJECTIVES

The specific objectives of this test were to:

1. Determine the time required for tool-to-tool changes.
2. Determine the time required to pick up and position, for transportation, a fully loaded (holding bucket, hammer, and plate) tool carrier.
3. Evaluate the tool carrier's suitability relative to excavator operation and tool retention during tool carrier transportation.

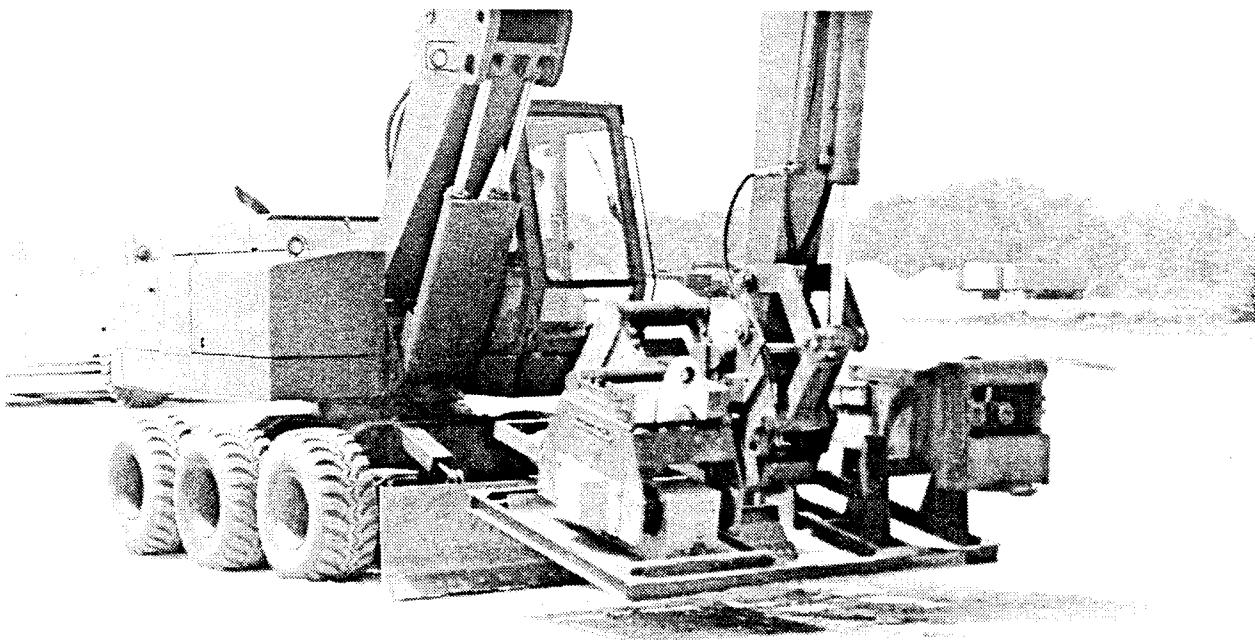


Figure C-1. RRR Excavator with Tool Carrier Attached

4. Evaluate the excavator's stability when carrying the fully loaded tool carrier on level and sloped surfaces.
5. Determine the ability of the hydraulic connection dust covers to keep contaminants out of the excavator's hydraulic system.
6. Determine the capability of the bucket's dirt shield to prevent dirt buildup around the excavator boom's hydraulic connections, which are not engaged when the bucket is being used.
7. Determine the hydraulic quick-connect's ability to function properly after 3 hours of use with the compaction plate and hammer.

#### D. TESTING MEASURES OF MERIT

For Objective 1, the average time for tool-to-tool changes must be 1 minute or less to be acceptable. For Objective 2, the average tool carrier pickup and positioning time must be 2 minutes or less to be acceptable. For Objectives 3 and 4, any loss of excavator control (maneuverability, braking, stability, etc.), or loss of tools while transporting the tool carrier, indicates unacceptable performance. For Objectives 5 and 6, a visible quantity of dirt under the hydraulic connection dust covers, or a dirt buildup on the unused male hydraulic connections on the excavator boom, respectively, constitute unacceptable performance. For Objective 7, any sustained hydraulic leaks or blowouts and/or tool failure resulting from the CONTEC system constitutes unacceptable performance.

## SECTION II

### TEST DESCRIPTION AND RESULTS

#### A. TEST LOCATIONS

Two test sites at Tyndall AFB, Florida were used during this test. For tool change time, tool carrier pickup and positioning time, hydraulic dust cover evaluation, bucket dirt shield evaluation, tool carrier transportation over level surfaces, and long-term compaction plate operation, the Small Crater Test Facility (SCTF) was used. For tool carrier transportation over sloped surfaces and long-term hammer operation, the Exploded Crater Test Facility (SKY TEN) was used.

Testing took place at the two test sites from 13 April to 16 October 1987. Testing was conducted by Air Force Engineering and Services Center (AFESC) in-house testing personnel.

#### B. TEST RESULTS

Test results are described below by individual test segments.

##### 1. Tool Change Time Testing - Phase I

This test segment involved placing one of the tools, already attached to the excavator's boom, on the tool carrier, then attaching another tool from the carrier to the boom. Elapsed time was measured from the moment the operator began placing the first tool on the carrier until the second tool was attached to the boom and was ready to use. A view of the tool-changing process is given in Figure C-2.

Table C-1 summarizes the results from the initial tool change time testing. Only one tool-to-tool change was completed in less than 1 minute; the compaction plate was replaced by the hammer in 49 seconds during Change 3. The average times for all tool-to-tool changes exceeded the 1-minute criterion from a minimum of 6 seconds (compaction-plate-to-bucket-changes) to a maximum of 1 minute and 25 seconds (hammer-to-compaction-plate changes). However, the 1-minute and 15-second overages were mainly attributable to the operator not positioning the excavator correctly on the first hammer-to-plate change. The remaining hammer-to-compaction-plate changes exceeded the 1-minute criterion by only 15 and 14 seconds, respectively.

Because of an error in the original installation of the hydraulic supply line, the CONTEC system required that the excavator blade be raised before tools could be exchanged. It was necessary to raise the blade to obtain sufficient hydraulic pressure to change the tools, i.e., to actuate the male hydraulic connectors on the excavator's boom. However, the excavator's hydraulic system was later modified to make raising the blade

unnecessary. The excavator operator estimated that this modification would save 10 to 20 seconds on tool-to-tool changes. Such a time savings would reduce the majority of times in Table C-1 to below the 1-minute criterion.

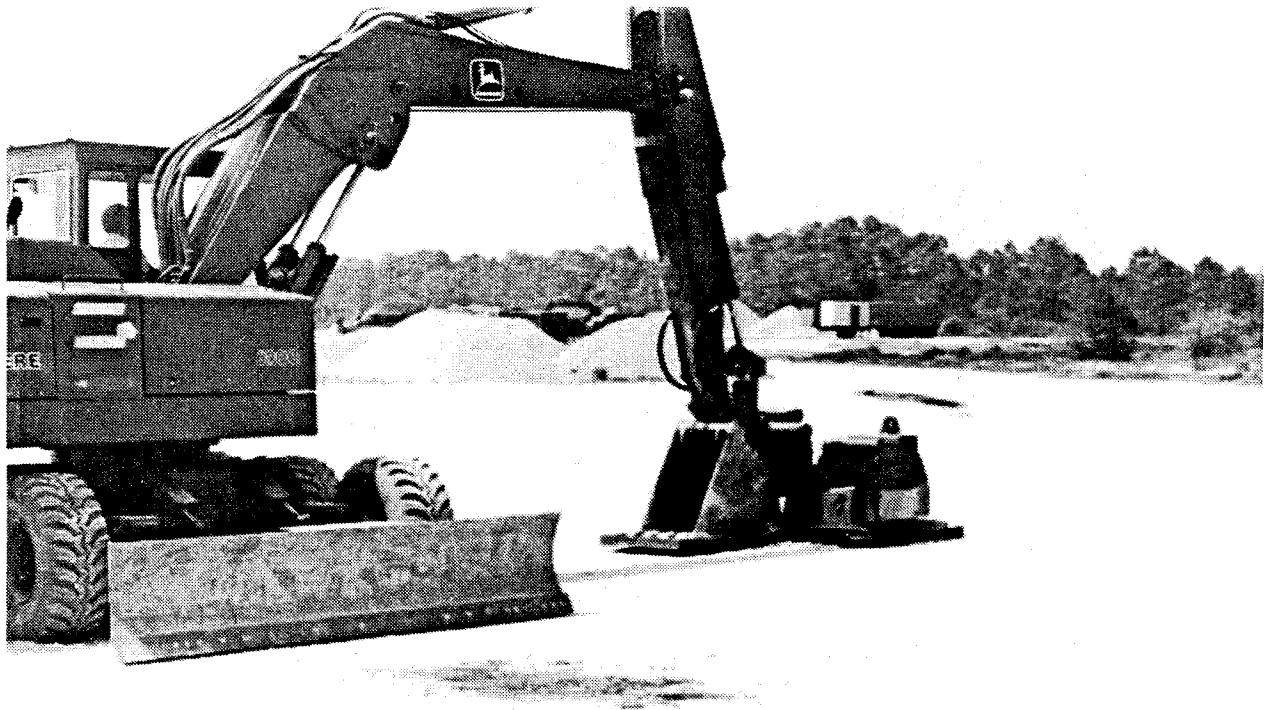


Figure C-2. View of Tool Changing Process

TABLE C-1. TOOL CHANGE TIMES

TOOLS CHANGED	CHANGE 1	CHANGE 2	CHANGE 3	AVERAGE CHANGE TIME
BUCKET TO PLATE	2 MIN 12 SEC	1 MIN 5 SEC	1 MIN 35 SEC	1 MIN 37 SEC
PLATE TO BUCKET	1 MIN 5 SEC	1 MIN 2 SEC	1 MIN 10 SEC	1 MIN 6 SEC
BUCKET TO HAMMER	1 MIN 38 SEC	2 MIN 3 SEC	1 MIN 41 SEC	1 MIN 47 SEC
HAMMER TO BUCKET	1 MIN 15 SEC	1 MIN 26 SEC	1 MIN 32 SEC	1 MIN 24 SEC
PLATE TO HAMMER	1 MIN 32 SEC	1 MIN 10 SEC	49 SEC	1 MIN 10 SEC
HAMMER TO PLATE	4 MIN 46 SEC	1 MIN 15 SEC	1 MIN 14 SEC	2 MIN 25 SEC

## 2. Tool Change Time Testing - Phase II

Additional tool-change time testing was done with the following changes:

- a. The excavator was modified so the blade would not have to be raised to use the CONTEC system, and

b. A modified tool carrier was used which canted the outer tools toward the center and made it possible to change tools without repositioning the excavator.

The modified tool carrier was fabricated by Foster Miller, Inc. as part of an independent quick-connect development contract. Results from this testing phase are summarized in Table C-2. As seen, change times were reduced substantially over the times given in Table C-1; times exceeded the 1-minute criterion in only a few instances. All average times were less than the 1-minute criterion.

TABLE C-2. ADDITIONAL TOOL CHANGE TIME TEST RESULTS

Operator	Tool Change Times*					
	<u>Plate To Hammer</u>	<u>Hammer To Plate</u>	<u>Bucket To Plate</u>	<u>Plate To Bucket</u>	<u>Bucket To Hammer</u>	<u>Hammer To Bucket</u>
1	0:30	0:57	0:59	1:41	0:43	0:44
	0:47	0:59	0:52	0:45	0:35	0:55
	0:57	0:47	0:52	1:00	0:42	0:35
	0:47	0:37	0:48	0:52	0:39	0:40
	0:42	0:33	0:41	0:50	0:41	1:36
	0:45	0:33	0:42	0:40	0:48	0:43
	0:38	0:32	0:36	0:40	0:51	0:47
	0:38	0:53	0:39	0:40	0:43	0:49
	0:42	0:36	0:55	0:47	0:44	1:05
	0:32	0:36	0:33	0:38	0:55	0:49
	<u>0:33</u>	<u>0:27</u>	<u>0:39</u>	<u>0:29</u>	<u>0:55</u>	<u>0:48</u>
Average:	0:41	0:41	0:45	0:49	0:45	0:52
<hr/>						
2	0:29	0:33	0:51	0:36	0:50	0:45
	0:32	0:33	0:37	0:48	0:38	0:44
	0:36	0:37	0:46	0:38	0:38	0:46
	0:38	0:41	0:37	0:54	0:53	0:44
	0:38	0:37	1:25	0:36	0:45	0:44
	0:33	0:35	0:32	0:31	0:38	0:43
	0:27	0:38	0:40	0:43	0:41	0:37
	---	---	0:49	0:39	0:37	0:47
	---	---	0:39	0:40	0:35	0:36
	---	---	0:43	0:36	0:32	0:37
	---	---	<u>0:33</u>	<u>0:34</u>	<u>0:38</u>	<u>0:41</u>
Average:	0:33	0:36	0:45	0:40	0:40	0:42

The CONTEC system requires the excavator operator to hold down a toggle switch in the excavator's cab to actuate the male hydraulic connectors on the boom into the female hydraulic connectors on the hammer or compaction plate tools. The operator did not always allow enough time to elapse before releasing the toggle switch. Consequently, the male hydraulic connectors were not always extended fully. This incomplete action may cause hydraulic leaks and/or cause the male connectors to back out from the female connectors during tool use.

Aligning the boom adaptor into the tool adapter was critical. There is approximately 11/32-inch leeway when aligning the hydraulic connectors of the boom with the tool's connectors. If the alignment is not correct, one or both of the following problems are likely to be encountered: (1) the top surface of male hydraulic connectors can be damaged, and (2) the hydraulic connectors may not latch together properly.

### 3. Tool Carrier Pickup And Positioning

This test segment involved placing one of the tools, already attached to the excavator boom, on the tool carrier, then picking up the carrier with the excavator's boom. Then the carrier was positioned in front of the excavator with one end of the carrier resting on the excavator's blade. Elapsed time was measured from the moment the operator began placing the tool on the carrier until the carrier was positioned in front of the excavator, ready for transportation. Figure C-3 shows the tool carrier pickup and positioning process.

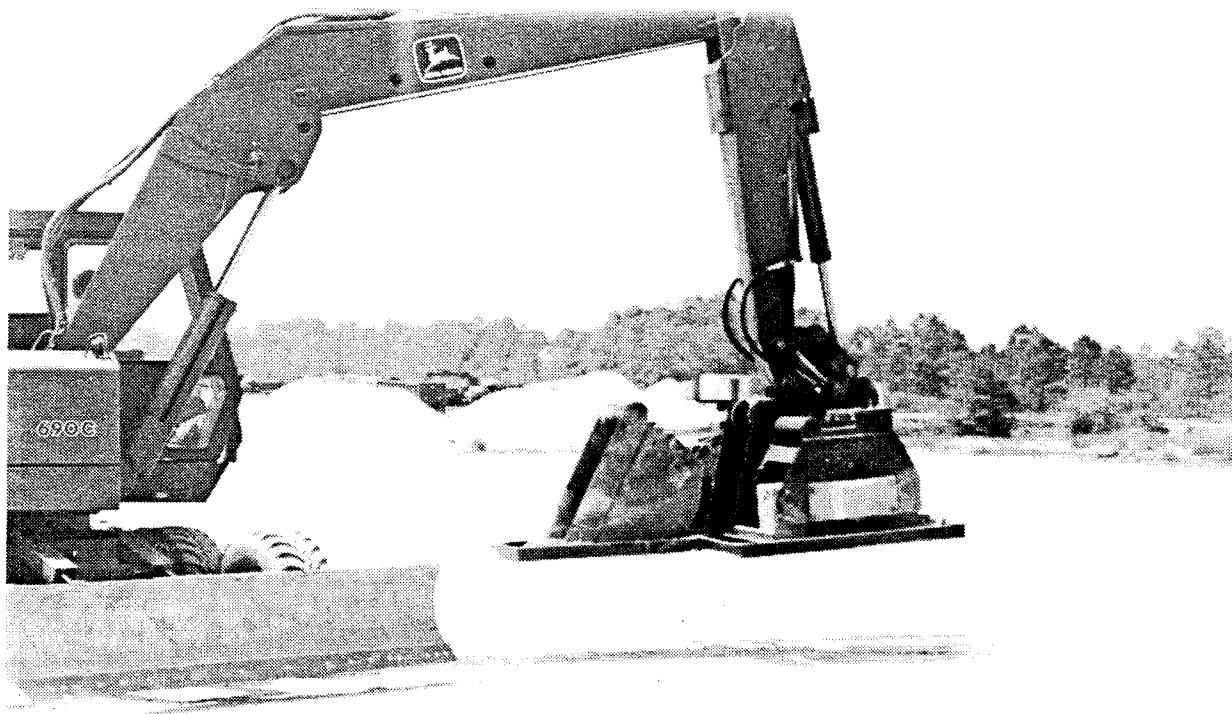


Figure C-3. Tool Carrier Pickup and Positioning

The tool carrier pickup and positioning tests were conducted before the hydraulic delay was corrected. As stated earlier, a delay in the original hydraulic system installation added an estimated 20 seconds to each tool change. Table C-3 summarizes the results from the tool carrier pickup and positioning testing. The average times for pickup and positioning only exceeded the 2-minute criterion when the hammer was placed on the carrier before picking up the carrier. The hammer was the most cumbersome tool, because its shape made it difficult for the excavator operator to determine when the hammer's far side was in the correct position over the carrier. The excavator operator stated that, with additional practice, the pickup and positioning time for the hammer could be reduced below the 2-minute criterion.

TABLE C-3. TOOL CARRIER PICKUP AND POSITIONING TIMES

<u>BUCKET PLACED ON CARRIER</u>	<u>PLATE PLACED ON CARRIER</u>	<u>HAMMER PLACED ON CARRIER</u>
1 MIN 40 SEC	2 MIN 2 SEC	2 MIN 43 SEC
2 MIN 5 SEC	1 MIN 48 SEC	2 MIN 18 SEC
1 MIN 38 SEC	1 MIN 50 SEC	1 MIN 57 SEC
1 MIN 47 SEC	1 MIN 51 SEC	2 MIN 11 SEC
1 MIN 25 SEC	2 MIN 2 SEC	2 MIN 12 SEC
1 MIN 19 SEC	1 MIN 51 SEC	1 MIN 50 SEC
1 MIN 18 SEC	1 MIN 55 SEC	2 MIN 17 SEC
<hr/>		
AVERAGES: 1 MIN 36 SEC	1 MIN 54 SEC	2 MIN 17 SEC

#### 4. Tool Carrier Transportation

This test segment involved transporting the fully loaded tool carrier over smooth and rough surfaces (level and sloped) to determine the excavator's maximum safe operating speed. Operator comments were used to determine when the excavator was beginning to approach an unstable condition. Before this point was reached, testing was stopped. The excavator speed at this point then was determined within approximately 0.5 mph. This determination was made by the gear in use and speed-versus-gearing data from the excavator operating manual.

Results from the tool carrier transportation testing are summarized below by surface type.

##### a. Smooth and Level Surface

The excavator's maximum safe speed over a smooth and level surface was approximately 6 mph in Gear II-Hi. However, caution must be used at this speed, because sudden braking could result in loss of control. Additionally, turns must be made widely and gradually to maintain stability and speed. Speeds

greater than 6 mph are not recommended, because the excavator may become unstable.

b. Rough and Level Surface

The excavator's maximum safe speed in Gear II-Lo under these conditions was from 3.2 mph (large bumps, depressions, and undulations in the surface) to 5 mph (small bumps, depressions, and undulations in the surface). However, once again, caution must be used at these speeds, because sudden braking could result in a loss of control. Additionally, turns must be made widely and gradually to maintain stability and speed. To maintain better control and to allow for sharper turns, speed should be reduced to approximately 2.5 mph (Gear I-Hi).

c. Sloped Surface

Testing under this condition was done on a 6.5-degree slope using the ramp to the SKY TEN test facility. The excavator's maximum safe speed in Gear II-Lo under these conditions was 3 mph. The excavator climbed and descended the slope without difficulty.

The excavator transported the tool carrier without major difficulty, consequently; the stated testing criterion was met. However, the carrier does push the excavator to within 90 percent of its load-carrying limit. As a result, transporting the excavator over a debris-covered pavement surface or severe slopes could be difficult.

Fatigue cracks in the carrier, where the bucket is stored for transportation, were discovered during testing. The cracks did not appear to jeopardize the carrier's structural integrity; however, future carriers should be reinforced to eliminate this problem.

5. Hydraulic Dust Cover Evaluation

This test segment involved placing sand on the hydraulic dust covers on the excavator boom and on each of the tools. The sand was placed to form a thick film on the covers. Then each tool was to be attached to the boom to determine if the sand got under the dust covers and into the excavator's hydraulic system. However, during the first part of testing, where the compaction plate was attached to the boom, damage occurred to the O-rings in the male hydraulic connectors. The O-rings were almost cut in half, resulting in a large hydraulic fluid leak. Consequently, further testing was terminated so the hydraulic system would not be damaged. The hydraulic dust covers did not perform satisfactorily.

## 6. Bucket Dirt Shield Evaluation

This test segment involved digging, then filling a 5-foot deep, 10-foot square hole in soft sand using the excavator bucket. After digging and filling was completed, the unused hydraulic connectors on the excavator boom were inspected to see if they had been contaminated by the sand. A small amount of sand accumulated on the connectors and could be brushed off easily. The bucket dirt shield performed satisfactorily.

## 7. Long-Term Compaction Plate Use

This test segment involved using the excavator compaction plate to compact a sandy soil area at the SCTF for 3 hours (Figure C-4). Two 20-minute rest breaks were taken after 1 and 2 hours of plate use. No problems occurred while using the compaction plate; the compaction plate performed satisfactorily.



Figure C-4. Long-Term Compaction Plate Use

## 8. Long-Term Hammer Use

This test segment involved using the excavator's hammer attachment to punch 8- to 10-inch deep holes in the pavement at SKY TEN for approximately 3 hours (Figure C-5). The pavement at SKY TEN consists of a 10-inch thick PCC pavement overlaid with 3 inches of asphalt. Because of mechanical problems with the excavator, unrelated to the CONTEC system, the 3-hour hammer test was completed in three segments.

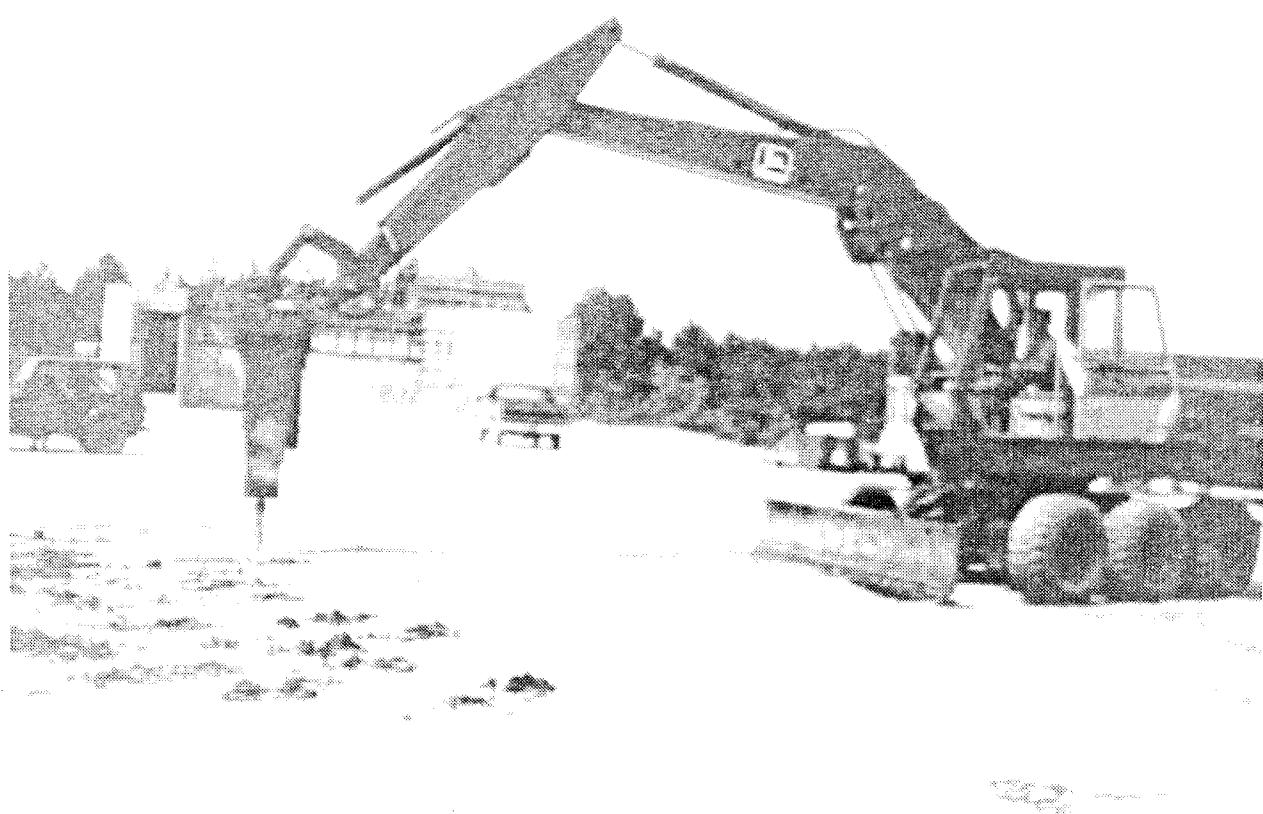


Figure C-5. Long-Term Hammer Use

On 17 April, 21 holes were punched in 45 minutes. The only problem related to the CONTEC system was a hydraulic leak from the boom's male hydraulic connectors. However, the leak appeared to be caused by the excavator operator not extending the connectors fully into the hammer during the attachment process. The leak did not appear to be caused by a system design flaw.

Hammer testing resumed on 20 April, and 52 holes were punched in 1 hour. The only problem was a hydraulic leak from the boom's male connectors. The leak appeared to be caused by the male connectors backing out from the female connectors on the

hammer during use. Reconnecting the hammer to the boom solved the problem. Testing was suspended after 52 holes because of an O-ring failure on the excavator boom, unrelated to the CONTEC system.

After the O-ring was replaced, 70 more holes were punched in 1 hour and 15 minutes. Once again, the boom's male connectors backed out from the female connectors on the hammer during use, causing a hydraulic leak.

Testing was terminated after an elapsed time of 3 hours, in which 143 holes had been punched in the pavement. The hydraulic quick-connect did not perform satisfactorily during the long-term hammer test because of the problems mentioned above. However, the representative from CONTEC indicated that the problems could be solved by adjusting the alignment of the hydraulic connectors on the boom and tool adapter. Correcting this would allow long-term hammer use to meet the stated performance criteria.

## SECTION III

### CONCLUSIONS AND RECOMMENDATIONS

#### A. GENERAL

The CONTEC system, while not meeting all test objectives, shows considerable promise in significantly reducing excavator tool change times. Consequently, it is recommended that the CONTEC system be modified, or another similar system be developed, and tested further.

#### B. SPECIFICS

The following, grouped by test segment, are major conclusions and recommendations resulting from this field test.

##### 1. Tool Change Time

The CONTEC quick-connect/disconnect system, in its initial configuration, did not meet the tool change time criterion of 1 minute; however, the CONTEC system was modified to improve its performance and, as a result, tool change times were less than the 1-minute criterion.

To further enhance tool change performance, it is recommended that the following modifications be made to the CONTEC system:

a. The toggle switch in the excavator cab should be modified so the operator does not have to hold it down while changing tools. Instead, the operator should have to press the switch only once to actuate the CONTEC system's hydraulic connectors for a set amount of time. In addition, a lock-unlock indicator is needed in the cab to verify the locked or unlocked status of the locking pin and hydraulic couplers.

b. A reliable, easy way to align the excavator boom to a tool during attachment is needed. As the CONTEC system was configured, alignment was difficult, making the excavator operator's skill critical to achieving tool change times of less than 1 minute. The modified tool carrier, used during the final timing tests, corrected this problem by canting the outside tools toward the center. In this configuration, the excavator can reach all three tools and properly align them without repositioning the excavator.

##### 2. Tool Carrier Pickup and Positioning

Under most circumstances, the excavator picked up the tool carrier and positioned it for transportation in less than the 2 minutes. However, it took longer than 2 minutes when the excavator had to place the hammer on the carrier before picking

the carrier up. Additional practice by the excavator operator should eliminate this problem. Consequently, the CONTEC system performed this task satisfactorily.

### 3. Tool Carrier Transportation

The excavator transported the tool carrier satisfactorily over smooth and rough terrain (level and sloped). No tools fell from the carrier, and the excavator's stability was acceptable. However, since the carrier imposes such a heavy burden on the excavator, it is recommended that use of a towed tool carrier be investigated. In any case, future carriers should be constructed so as to eliminate the stress cracking observed during testing.

### 4. Hydraulic Dust Cover Evaluation

The hydraulic dust covers did not perform satisfactorily during testing. Based on these findings, it is recommended that, when using the CONTEC system, the excavator operator ensure that there is no dirt or debris on the dust covers before attaching a tool. Failure to do so may result in contamination of the hydraulic couplers or the hydraulic tool.

### 5. Bucket Dirt Shield Evaluation

The CONTEC system's bucket dirt shield performed satisfactorily during testing.

### 6. Long-Term Compaction Plate Use

The CONTEC system performed satisfactorily during long-term compaction plate use.

### 7. Long-Term Hammer Use

The CONTEC system did not meet the test criterion regarding long-term hammer use. The boom's male hydraulic connectors backed out from the female connectors on the hammer when the hammer was punching holes in pavement, causing a hydraulic fluid leak. It is recommended that better ways to align the male and female connectors be investigated and tested.

### 8. Recommendation for Additional Testing

Before the CONTEC system is fielded it should be tested thoroughly in an operational environment. Such testing should stress the quick-connect system more fully to identify any additional problems and needed modifications.